THE LIBRARY
OF
THE UNIVERSITY
OF CALIFORNIA
DAVIS

STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISIONS OF ENGINEERING AND IRRIGATION AND
OF WATER RIGHTS

TC824
C2
A2
no. 11

BULLETIN No. 11

Ground Water Resources of the Southern San Joaquin Valley

By
S. T. HARDING
Consulting Irrigation Engineer

CALIFORNIA STATE PRINTING OFFICE
CHARLES A. WHITMORE, State Printer
SACRAMENTO, 1927

47676

LIBRARY
UNIVERSITY OF CALIFORNIA
DAVIS

TABLE OF CONTENTS.

	Page
CHAPTER I. INTRODUCTION AND SUMMARY	7
Introduction	7
Summary of Main Report	12
Summary of Chapter III—Ground Water in Kings River Area	14
Summary of Chapter IV—Ground Water in Tulare County Areas	17
Kaweah River Areas	17
Areas Dependent on Tule River	19
Deer Creek Area	20
White Creek Area	20
Summary of Chapter V—Ground Water in Kern County Areas	20
CHAPTER II. GENERAL DESCRIPTION OF SOUTHERN SAN JOAQUIN VALLEY	23
Data Available on Ground Water	23
Maps Delineating Ground Water Conditions	24
General Ground Water Conditions	27
Ground Water as a Source of Irrigation Supply	27
Climate	28
Soils	28
Water Supply	28
Use of Surface Water Supply	30
Areas Irrigated	30
Value of Agricultural Products	32
Geology	32
Quality of Ground Waters	34
CHAPTER III. GROUND WATER IN KINGS RIVER AREA	37
Growth of Pumping from Ground Water	39
Methods of Analysis of Ground Water Conditions	40
Ground Water in the Fresno Irrigation District	42
Ground Water Fluctuations from December 1 to March 1	45
Ground Water Fluctuations March 1 to December 1	47
Ground Water in the Consolidated Irrigation District	56
Ground Water Fluctuations December 1 to March 1	57
Ground Water Fluctuations March 1 to December 1	57
Ground Water in Laguna Irrigation District	62
Ground Water in Riverdale Irrigation District	62
Ground Water Supplies in Kings River Areas not Directly Served by Canals	63
Ground Water in Foothill Irrigation District	66
Ground Water in the Alta Irrigation District	67
Ground Water Fluctuations from December 1 to March 1	67
Ground Water Fluctuations March 1 to December 1	68
Ground Water in Area Under Kings County Canals	73
Lemoore Canal Area	74
Last Chance Area	75
People's Ditch Area	75
Ground Water in Valley Trough Areas Along North Side Channels of Kings River	76
Cuthbert-Burrell Area	76
Stinson Irrigation District	77
Crescent Irrigation District	77
James Irrigation District	77
Summary	78
Ground Water in the West Side Area from Tulare Lake to Mendota	79
Ground Water in the Tulare Lake Area	80

Page
CHAPTER IV. GROUND WATER IN TULARE COUNTY AREAS 83
Ground Water in Kaweah River Areas 84
Ground Water in the Main Area of Kaweah Delta Covered by Canals Diverting for Lands Below Venice Hills 88
Ground Water in the Areas Covered by Canals Diverting for Lands Mainly Above Venice Hills 92
Ground Water in the Area West of Lindsay-Strathmore Irrigation District Toward Which Ground Water Slopes from Kaweah Delta 93
Ground Water in the Area of Lower Kaweah Delta Outside of Areas Covered by Canals 95
Ground Water in the Area of Lindsay-Strathmore Irrigation District 96
Ground Water in Areas Dependent on Tule River for Their Water Supply 96
Ground Water in Main Tule River Area Including the Areas Within Which Some Lands Receive Canal Irrigation from Tule River 98
Ground Water in Area on North of Tule River Delta 102
Ground Water in South Tule Area 103
Ground Water in Outer Tule River Area 103
Ground Water in Deer Creek Area 107
Ground Water in White Creek Area 110

CHAPTER V. GROUND WATER IN KERN COUNTY AREAS 115
Rates of Pumping Draft 115
Ground Water in Area Above the East Side Canal 116
Ground Water in East Side Canal Area 121
Ground Water in Main Canal Area South of Kern River 124
Ground Water in Areas North of Kern River 125
Ground Water in Rosedale Area 125
Ground Water in Shafter, Wasco and McFarland Area 131
Ground Water in Northern Kern County Area 142
Ground Water in Pioneer Canal Area 142
Ground Water in Valley Trough Areas South of Tulare Lake 143

LIST OF FIGURES.

PAGE

Fig. 1. Growth in use of power by agriculture for pumping in Dinuba, Fresno and Selma Districts of San Joaquin Light and Power Corporation ------ 38
Fig. 2. Comparison of ground water levels 1907–1926 in Fresno Irrigation District ------ 44
Fig. 3. Relation of change in level of ground water during December, January and February to rainfall during the same months in Fresno Irrigation District ------ 46
Fig. 4. Relation of volume of water diverted by canals to change in level of ground water in areas under canals in Fresno Irrigation District ------ 48
Fig. 5. Hydrographs of typical wells in Fresno Irrigation District ------ 52
Fig. 6. Relation of change in level of ground water during December, January and February to the rainfall during the same months in the Consolidated Irrigation District ------ 58
Fig. 7. Relation of volume of water diverted by canals to change in level of ground water in areas under canals in Consolidated Irrigation District ------ 59
Fig. 8. Hydrographs of typical wells in Consolidated Irrigation District ------ 60
Fig. 9. Change in level of ground water since November, 1921, in shallow wells of James Irrigation District and wells in adjacent areas in the Fresno Irrigation District ------ 64
Fig. 10. Relation of change in level of ground water during December, January and February to the rainfall during the same months in the Alta Irrigation District ------ 69
Fig. 11. Relation of volume of water applied in irrigation to change in level of ground water during period March 1 to December 1, in areas in Alta Irrigation District ------ 70
Fig. 12. Hydrographs of typical wells in Alta Irrigation District ------ 72
Fig. 13. Relation between canal diversions and change in level of ground water in Lemoore Irrigation District in 1925 ------ 75
Fig. 14. Relation of canal diversion to change in level of ground water in area served by Last Chance Canal in 1925 ------ 76
Fig. 15. Hydrographs of typical wells in main area of Kaweah Delta ------ 90
Fig. 16. Hydrographs of typical wells in outer areas of Kaweah Delta ------ 94
Fig. 17. Hydrographs of typical wells in Main Tule River Area ------ 100
Fig. 18. Hydrographs of typical wells in outer Tule River Area ------ 104
Fig. 19. Hydrographs of typical wells in Deer Creek Area ------ 108
Fig. 20. Hydrographs of typical wells in White Creek Area ------ 112
Fig. 21. Hydrographs of typical wells in the area above the East Side Canal ------ 118
Fig. 22. Hydrographs of typical wells under East Side Canal ------ 122
Fig. 23. Hydrographs of typical shallow wells in main area south of Kern River 126
Fig. 24. Hydrographs of typical wells in the Rosedale Area ------ 127
Fig. 25. Relation of water applied in irrigation from both canals and wells to change in level of ground water in Rosedale Area ------ 130
Fig. 26. Relation of water applied in irrigation from both canals and wells to change in level of ground water in Shafter, Wasco and McFarland Areas ------ 135
Fig. 27. Hydrographs of typical wells in Shafter and Wasco Areas ------ 138
Fig. 28. Hydrographs of typical wells in McFarland Area ------ 140
Fig. 29. Hydrographs of typical wells in Goose Lake Slough and Buttonwillow Areas ------ 144

LIST OF MAPS.

Map I. Ground water contours, U. S. G. S. datum, as of October, 1925, in southern San Joaquin Valley ------ In pocket
Map II. Depth of ground water, as of October, 1925, in southern San Joaquin Valley ------ In pocket
Map III. Lowering of ground water for the five-year period 1920–1925 in southern San Joaquin Valley ------ In pocket

CHAPTER I.

INTRODUCTION AND SUMMARY.

Introduction.

The Southern San Joaquin Valley, as the term is used in this report, includes the portion of the San Joaquin Valley from the San Joaquin River south. The available local surface and underground water supplies are more completely utilized in this area than in other parts of the San Joaquin or Sacramento valleys. The rapid increase in the pumping of ground water in recent years makes it desirable to consider the extent of the ground water supply.

Most of the Southern San Joaquin Valley is underlaid by ground water within depths which make pumping profitable. The data assembled for this report shows that of the total area of 1,370,000 acres irrigated in this area, 800,000 acres secure all or part of their water supply by pumping from wells. For about 400,000 acres the entire irrigation supply is secured from wells, for the remaining 400,000 acres the pumping supplements supplies secured from canals.

The Southern San Joaquin Valley represents one of the most highly developed agricultural sections in the state. The area irrigated is over one-fourth of the total for the state. The value of the agricultural products is probably an even larger proportion of the total value of irrigated crops. All classes of irrigation practice are represented, varying from citrus, vineyards, deciduous orchards, melons, lettuce, cotton and cereals to the crude flooding of pasturage. Owing to the limited rainfall in the valley areas practically all agriculture depends on irrigation, dry farming being limited in extent and uncertain in results.

The gross area of valley lands in the Southern San Joaquin Valley is 4,000,000 acres. There is in addition about 350,000 acres of adjacent higher plains areas suited to irrigation if water can be made available. Present irrigation represents less than one-half of the valley land of a quality suited for irrigation. With the available local sources of water supply very largely utilized for the irrigation of present areas, the importance of detailed study of the present use and the opportunities for increased use is apparent. The complete use of surface sources of supply is being planned where opportunities for additional development, largely through storage, occur. This report is limited to a consideration of ground water supplies and use as the full utilization of such supplies is as desirable as is the use of the surface streams. However, while all increases in use for which local ground water supplies are available is desirable, it is equally desirable that additional development should not be undertaken unless a water supply for its permanent support is available.

Canal irrigation began over fifty years ago; pumping is a relatively recent development. In the earlier period of use of ground water little effect on the ground water elevation was noticed as the draft was small in proportion to the total areas affected. In recent years the lowering of the ground water in some parts of the area has become serious and doubts have arisen regarding the permanence of the supply.

This report is the result of an effort to determine the relation of present use to the available supply.

Ground water supplies are local in character. The greater portion of this report consists of a detailed discussion of the ground water conditions in the different parts of the area. Such discussions are based on the available ground water records which cover periods varying from one to six years in the different parts of the area. The present discussions are of the nature of a progress report and any conclusions expressed are necessarily subject to modification as records covering longer periods of time become available. Well measurements should be continued and extended so that sufficient data may be accumulated for drawing final conclusions. It is considered that the general conclusions stated are adequately supported by the present records. Further experience may result in changes in some of the details of the conclusions regarding local areas. The extent of the dependence on the use of ground water in this area makes it essential that the collection of adequate records be continued in order that the effects of present use may be observed and the limits of feasible development more definitely determined.

While ground water may extend generally under relatively large areas, it moves slowly and the replacement of water that has been removed by pumping takes place similarly slowly unless streams or canals are close at hand. It is because of these conditions that a comparison of the average supply available and the total draft for a large area gives little indication of the conditions in different parts of the area. The greater portion of this report represents an effort to present the local conditions in the different parts of the Southern San Joaquin Valley. In this introduction it is only desired to present the conclusions reached. The support for the statements made will be found in the detail discussion in the main portions of the report and is not repeated here.

The total mean annual stream flow tributary to the Southern San Joaquin Valley is 3,300,000 acre-feet. The present irrigation development from both canals and pumping represents one acre irrigated for each 2.4 acre-feet of mean annual water supply. This is a more complete use of local water supplies than is found in any other similarly large part of the San Joaquin or Sacramento valleys. The only local water supplies unused in the Southern San Joaquin Valley are the excess stream flow in years of more than normal precipitation. There has been practically no unused run-off from 1923 to 1925, inclusive. Only about fifteen per cent of the total average run-off now escapes from this area through the San Joaquin River or is lost as excess evaporation from Tulare Lake. Plans are being made for works which will result in the use of much of this excess. Practically all water that can be used without storage has been and is being utilized for some type of irrigation. The area as a whole has been and is utilizing its locally available supplies. Further development will be as largely by improvements in present practices as it will be by the additional use of local supplies now unused. Local supplies can never supply the available irrigable area as the total locally tributary mean annual stream flow is less than one acre-foot per acre of irrigable land.

This is a scant half of the supply required for the full development of the area.

Of the total area of 800,000 acres now receiving entire or partial ground water supplies, an area of about 180,000 acres is considered to be supplied from ground water sources where the extent of the present draft exceeds the average rate of replenishment of the supply. This area is the sum of smaller areas in different parts of the Southern San Joaquin Valley and is all in areas outside of those receiving canal service. Further increase in pumping will result in an extension of these conditions to other areas as only a portion of their gross area is now irrigated. An attempt to irrigate additional lands by pumping in many areas now partially served by canals will result in some cases in a draft in excess of the supply with a consequent progressive ground water lowering.

Much of the area of 180,000 acres which it is considered is drawing on its ground waters at a rate in excess of its supply has possible means of relieving this condition by changes in the present use of the local stream flow. These consist of areas where by storage or transfers in place of use of present canal diversions, water may be made available from canals to replace present pumping directly or where the irrigation by canals of new areas will make available additional ground water supplies for present pumping. Such means may relieve the present overdraft in about one-half of this area of 180,000 acres.

From one-half to two-thirds of the area of overdraft is pumping from wells that are distant from active local sources of ground water replenishment or in areas where local supplies are already overtaxed. Only continued lowering of the ground water can be expected in such areas if present conditions of use and supply continue. These areas are not confined to any one part of the Southern San Joaquin Valley but occur on both the east and west sides of the valley and in each of the three main divisions discussed, namely, the Kings River areas, Tulare County and Kern County. In some areas distant from local streams of adequate size the irrigation of only a small per cent of the gross irrigable area has resulted in progressive ground water lowering. Other areas are above the lands to which the streams' flow is diverted and in consequence receive a limited replenishment which has already been drawn upon in excess of its extent.

Due to the large areas of irrigable land not now developed much opportunity for additional pumping exists in nearly all areas. In the areas already overdeveloped much good land remains on which the owners may drill wells and secure satisfactory rates of discharge. Under the system of rights to the use of ground water now in use in California each overlying land owner has an equal right to secure ground water in proportion to his needs. Additional development would only result in an increase in the rate of lowering. Such additional development has occurred in the past whenever the prospect of favorable crop prices has resulted in an increased demand for irrigated land. The extent of the possible increased draft with its unfavorable effect on those now pumping in areas of present overdraft is apparent when it is realized that in several of these areas, the pumping for less than one-fourth of the gross irrigable area has resulted in a draft in excess of the supply. In some areas now receiving canal service the extent of the combined canal and ground water supplies is only sufficient for the irrigation of about one-half of the gross irrigable area affected. The attempt to irrigate the remainder of these areas would result in similar conditions of overdraft.

Much misunderstanding has been found in regard to the relation of the discharge of individual wells and the general conditions of ground water supply and draft in an area as a whole. Because wells can be drilled from which a good rate of flow can be obtained does not mean that the ground water supply is ample or that it will maintain its level under continued use. The discharge of a well depends upon the character of the materials which it penetrates. If such materials are coarse and freely water yielding, a relatively large discharge may be secured with a small amount of drawdown while pumping. The amount of water that can be drawn from a well while pumping is not a measure of the amount of water that moves into the area from whatever sources of supply may be tributary to that area. To install pumps having a total capacity in excess of the average rate of replenishment can only mean a depletion of the accumulated ground water within the area.

When the pumping draft in any area exceeds the average ground water supply, the draft in excess of the supply is taken from the ground water accumulation under the area. This results in the lowering of the ground water, the increase in pumping lift and costs and the replacement of the original pumping equipment by types of pumps adapted to use under the increased lift. The lowering increases both the investment in pumping equipment and the costs of operation. If such lowering continues, the increase in the pumping lift will eventually become so large that there is no longer a profit from pumping. The time required for this condition to be reached depends on the original depth to ground water, the rate of lowering and the profit from the use of water. Fortunately much of the area in the Southern San Joaquin Valley had ground water at shallow depths before pumping began so that relatively large amounts of lowering may occur before pumping becomes unprofitable. However, the lowering has, in some areas, already been sufficient so that little profit remains from pumping for crops of lower value.

If overdraft continues, the resulting lowering will cause a gradual decrease in pumping as the less efficient and more expensive plants cease to be profitable. Such a process will eventually result in the survival of the fittest with a draft reduced to what the available supply can support. However, the path to this result is strewn with the wreckage of the farms and homes of those who attempted development and could not survive. Even the survivors gain little beyond mere existence as the ground water is lowered to a point where little profit in its use remains. Fully as large permanent usefulness from a ground water supply could be gained by limiting the draft to the amounts which the available supply could maintain without overdraft and lowering. Such a limited draft would enable all pumping to be practiced with smaller lifts and greater profit. Under our existing principles of rights to the use of ground water where each owner of land overlying a source of ground water supply has an equal right to participate in its use, there is no means by which the draft can be limited to the supply, as in all areas in the Southern San Joaquin Valley outside of some of those served by canals the ground water is insufficient to supply all of the overlying areas.

The above picture of the results of overdraft on a ground water supply is not a fanciful one. It has occurred in other areas in this state and is beginning to occur in parts of this area. With the lowering that has occurred in some areas, the lift has approached a point where little profit remains in crops of larger use and lower value. While on the whole an increase in numbers of plants and use is continuing in this area, in some portions some plants operating in previous years were not operated in 1925. With many plants facing the expense of changing the type of pump used, abandonment of operation can be anticipated in additional cases. If the present extent of use is continued the records now available indicate that an area now developed of about 100,000 acres will eventually revert to waste land. The time when this condition will be reached can not be predicted with any definiteness, as such a prediction includes the elements of value of the crops grown as well as the rate of ground water lowering. It is being approached now in the least favorably situated parts of the area; it will be a matter of many years in the more favorable areas where the rate of overdraft is small.

Ground water supplies are like surface water supplies; they have a source and the amount of use that can be maintained permanently is limited to the extent of the supply. With ground water supplies it is more difficult to determine the source and to measure the extent of the supply, but such difficulties do not alter the fact that there must be a source and that the amount of the supply has a limit. There are various ways of estimating both the source and the extent of ground water supplies. Prior to actual use of ground water in any area such methods are generally indirect. After pumping has been practiced, the results of such use furnishes the best basis for estimating the amount of draft which can be maintained. This method has been used in this report.

Various theories have been advanced regarding the source of ground water in this area. All available records indicate that there is only one source, namely, the run-off resulting from the precipitation on the locally tributary drainage areas. Except for minor amounts of such run-off from the lower hill areas, all of the locally tributary run-off occurs in definite stream channels in which it can be and has been measured. These records enable the average total water supply of the area to be determined within relatively narrow margins of uncertainty.

The larger part of the run-off reaches this area through streams draining the higher areas of the Sierras. Kings River supplies one-half of the total, Kern River about one-fourth; the other larger streams in the order of their size are Kaweah and Tule rivers. Each stream enters the valley over a delta which has been built up by the materials it has transported. Within each delta the ground water has its source in its local stream. Being relatively close to this source and of coarser materials, the deltas contain ground water in larger amounts, and under more readily obtainable conditions than in the more distant areas.

The stream deltas extend out into the valley for various distances depending on the size of the stream. Kings River delta extends practically across the valley and has shut off outflow to the north from the other streams. In the floor or trough of the valley the ground waters derived from the different streams mingle and the source of the supply of any local portion of the valley trough is more difficult to determine. The streams from the Sierras enter the valley too far apart for their deltas to meet near the upper edge of the valley. In consequence there are many areas into which the percolation from the larger streams or from canals does not penetrate. Such areas have only limited sources of ground water supply and extensive pumping has always resulted in a relatively rapid ground water depletion.

All areas in the Southern San Joaquin Valley need give serious attention to their ground water situation. If the records obtained show that the development has not reached a point where the draft exceeds the supply, the advantage of such knowledge will more than repay the effort required for its determination. If it is found that present development is approaching or has exceeded the available supply, efforts toward limiting further development and toward higher standards of practice with consequent reduction in draft for present areas will extend the time before ground water lowering may result in the abandonment of pumping plants and the decrease in the irrigation development of such localities. Ground water is mysterious only to such extent as actual information regarding it is unknown. Each locality should see that its ground water history is recorded through well measurements in order that uncertainty as to what has occurred and is occurring is not added to the uncertainties of prediction as to what will occur.

Summary of Main Report.

The experience in the use of ground water in the Southern San Joaquin Valley emphasizes certain results. One of these is that ground water which does not have a direct and local source of replenishment will not maintain a heavy draft without progressive lowering. Ground water movement occurs slowly and in limited amounts. Extensive use of ground water except in areas having such direct sources of supply has resulted in lowering of the ground water in all cases. Distant movement, over relatively long periods, in the past has resulted in the accumulation of large amounts of ground water under large areas in the Southern San Joaquin Valley. However, when such ground waters are drawn upon to irrigate more than a small fraction of the gross overlying area, the rate of draft exceeds the rate of replacement, the ground water storage is drawn upon and lowering results.

Another fact brought out by the experience in this area is that on the larger delta areas the principal source of ground water supply is the losses from water diverted from the streams rather than the seepage from the stream channels themselves. One-half the pumping is on lands also receiving some canal service. For such lands the ground water fluctuates as it is more heavily drawn upon in years of deficient canal supply but may be restored in years of larger canal use. Of the pumping area for which it is considered present draft exceeds the ground water supply, only a small portion is in areas receiving canal service. As a source of supplemental water supply in areas receiving partial canal service, pumping represents a very effective and desirable type of storage. Where the canal supplies are adequate in amount but occur only during a short diversion season, full irrigation of the entire area can be accomplished by such supplemental pumping. Where the total canal supplies are insufficient, permanent development can not support all of the gross area.

Another point which the records assembled in the preparation of this report enables to be estimated is the rate of supply required to provide the moisture requirements of the crops. In many areas the supply received, the area cropped and the resulting effect on the ground water have been observed for several years. These results provide a basis on which to estimate the water consumed by different crops under different conditions. If the ground water is to be maintained in any area, the average supply received must be equal to the use by the crops and any outward ground water movement. Records to date from different areas indicate as tentative conclusions that in areas of trees and vines having limited ground water outflow, the crop needs for moisture will be supplied by an average annual delivery into the area of about $1\frac{2}{3}$ acre-feet of water per acre of crop. For forage crops an average delivery of 2 to $2\frac{1}{4}$ acre-feet of water per acre of crop may be required. For other crop conditions other amounts of supply are found. The results for different parts of the area are discussed in detail in the report. Where ground water outflow occurs or where the ground water is close to the ground surface larger amounts of supply are required to supply the crops and maintain the ground water.

The general ground water contours which represent the elevation and slope of the ground water table are shown on Map 1. The depths to ground water are shown on Map 2. The extent to which the ground water has lowered from 1920 to 1925 for the areas in Tulare and Kern counties for which records covering this period are available are shown on Map 3. The details regarding these maps are explained in Chapter II.

The ground water is discussed separately for three divisions of the area. These are the Kings River areas, the Tulare County areas and the Kern County areas. Each of these three areas are relatively distinct in their ground water supply and use. Within each area, the different localities also have distinct ground water conditions and each area is further subdivided for detailed discussion. In considering these sub-areas, it should be kept in mind that the discussions of the relation of surface water supply and ground water fluctuation are based upon the records of from one to six years. Altered conditions in adjacent territory, from those obtaining during the period of record may effect the relation here discussed. However, a study of the available data discloses no reason to expect large changes. Also it is desired to point out that the discussions apply to average conditions in each sub-acrea and may not express the true relation in each individual part.

SUMMARY OF CHAPTER III.

GROUND WATER IN KINGS RIVER AREA.

The Kings River area includes those areas whose ground water is derived mainly or wholly from Kings River either directly or by diversion therefrom by canals. It includes Tulare Lake and the areas west of the valley trough from the southern part of Tulare Lake to Mendota. In years of average stream flow a total area of over 600,000 acres receives canal irrigation from Kings River. Of this area fully one-half is also supplied with pumping plants from which supplemental ground water supplies are secured. There is an additional area of 130,000 acres which secures its water supply entirely by pumping. As the mean annual run-off of Kings River is about 1,800,000 acre-feet, the total water supply from Kings River represents an average of only 2.4 acre-feet per acre of present total irrigation development.

Fresno Irrigation District.

In the Fresno Irrigation District the canal service is more regular and extends over a longer season than that secured by areas having later priorities of water right. Of the total area in the district of 240,000 acres, 163,000 acres are irrigated from canals and 31,000 acres entirely by pumping. The area supplied by canals is also largely supplied with pumping plants for supplemental pumping. The ground water fluctuates with the extent of the canal supply during the season from March 1 to December 1. During the remaining winter months the ground water fluctuations are not dependent on the canal diversions of the preceding season but appear to vary with the amount of the rainfall during these months. For the different parts of the district an average canal delivery varying from 1.65 to 2.25 acre-feet per acre of the total area of irrigated crops appears to be required to supply the crop needs and maintain the ground water. The variations in these requirements are the result of the character of the crops, the ground water movement into or out of the different areas and the height of the ground water.

Ground water in the Fresno Irrigation District occurred at depths of about sixty feet prior to irrigation. Following the use of water from canals the ground water rose until it stood less than six feet below the ground surface under much of the district. From December 1, 1921, to December 1, 1925, there has been an average lowering of 1.75 feet for the two-thirds of the area in the district under the Fresno Canal. The lowering averaged 3.75 feet in the very dry year of 1924. In 1925 the ground water recovered an average of 1.4 feet.

The Fresno City Water Corporation pumps about 20,000 acre-feet per year from an area of about 6000 acres within the city of Fresno. This has resulted in a lowering of the ground water within the city of as much as fourteen feet below its former elevation. A portion of this draft is delivered to the irrigated area southwest of Fresno through the discharge of the city sewage.

The present extent of pumping in the Fresno Irrigation District is considered to be adequate to control the ground water so that a recurrence of the former conditions of injury from lack of drainage is not anticipated. In addition to supplying needed water for irrigation, pumping has been of much benefit in supplying drainage.

Consolidated Irrigation District.

In the Consolidated Irrigation District, of the gross area of 150,000 acres, 81,500 acres are irrigated from canal service and 44,000 acres are supplied entirely by pumping. In addition the larger part of the canal-served area has supplemental pumping plants. The ground water records indicate some movement from the higher toward the lower area. Present records indicate that this may amount to about 0.35 acre-feet per acre from the upper area toward the lower. Winter fluctuations are proportional to the winter rainfall. The rate of delivery required per acre of total irrigated crop appears to be partially dependent on the height of the ground water. A smaller requirement appeared to be required under the lower ground water conditions in 1925 than those of 1922 and 1923. For the entire district, an average delivery of 1.75 acre-feet per acre of total canal and pump irrigated area appears to be required to supply the crops and maintain the ground water. The ground water has lowered an average of three feet from 1921 to 1925. The ground water lowered 3.8 feet in 1924 and rose 0.5 foot in 1925.

Laguna and Riverdale Irrigation Districts.

In the Laguna and Riverdale Irrigation districts less extensive ground water records are available. In 1924 about forty per cent of the irrigated area was supplied with pumping plants. Inexpensive, shallow wells and plants are obtainable in these districts.

Areas Not Directly Served by Canals.

There is an area of about 180,000 acres lying between the Fresno and Consolidated Irrigation districts and the areas supplied by diversion from Murphy and Fresno sloughs in which there is very little irrigation. Ground water has stood relatively close to the ground surface over much of this area. The James Irrigation District has a series of pumping plants in this area. The water secured is used within the district. These wells have been operated since 1921. A total draft of 61,000 acre-feet to the end of 1925 had resulted in an average ground water lowering of about five feet at the wells. These wells do not appear to fluctuate directly with the wells in the adjacent parts of the Fresno Irrigation District. Ground water movement from the higher areas to the east is considered to occur at a relatively slow rate.

Foothill Irrigation District.

Of the 56,000 acres in the Foothill Irrigation District about 20,000 acres are now irrigated from wells. This district has received no canal supplies in the past. The ground water has lowered over fifty feet in some parts of the area. The local sources of ground water supply are inadequate to meet the present draft and additional supplies are being sought by the district.

Alta Irrigation District.

The Alta Irrigation District comprises 129,000 acres of which about 82,000 acres are now irrigated. Practically all of the irrigated area receives canal service, only a small area depending entirely on pumps. Nearly all of the canal-served area also secures supplemental supplies from wells. The ground water in the winter fluctuates with the amount of the winter rainfall. The average rate of delivery per acre of crop required to supply crop needs and maintain the ground water as indicated by present records appears to vary from 1.4 to 2.25 acre-feet in different parts of the area. The larger requirement is for areas along Kings River where outward movement of ground water occurs.

The ground water in the Alta District has lowered an average of 7.5 feet from 1921 to 1925. The lowering in the very dry year of 1924 averaged 9.8 feet; in 1925, 1.9 feet of this lowering was recovered. The records indicate that a smaller rate of delivery will meet crop needs and maintain the ground water with the lower ground water as in 1925 than for the conditions of 1922 and 1923.

Kings County Canals.

Less extensive records are available regarding the ground water fluctuations under the Peoples, Last Chance and Lemoore canals in Kings County than for the upper districts. Records in 1925 for the Lemoore Canal area show a small rise in the ground water with an average delivery of 1.8 acre-feet per acre of gross area. For the Last Chance canal area with a larger proportion of trees and vines an average canal supply of 1.9 acre-feet per acre of gross area resulted in a ground water rise of about one foot. Ground water in all of these areas is relatively close to the ground surface, being generally less than ten feet below the ground surface in 1925 after the very dry year of 1924. All of the lands in these areas are reported as irrigated, incomplete irrigation of pasturage occurs on much of the area.

Valley Trough Areas on North Side.

The valley trough area along the north side channels of Kings River includes lands served by a number of small canal systems. Pumping from within the area is largely from deeper wells. Such wells were formerly artesian but now flow, if at all, only during winter months of small draft. The quality of the water secured in variable. Some wells yield water whose continued use might result in soil injury if used as the entire source of supply. As all lands secure some canal supplies and use pumping from wells as a supplemental source, such injury is not probable. The deeper wells are relatively sensitive to draft and the extent of pumping which can be maintained without excessive lifts appears to be smaller than that feasible in areas of shallow supplies more directly replenished. The source of the supply for the deeper wells is distant from the trough area and is not definitely known. The deep well supply is probably obtained from areas along the course of Kings River above these lands.

West Side Areas.

West of the valley trough extending from Tulare Lake to Mendota is a gross area of 250,000 acres, about one-eighth of which is now irrigated from local deep wells. These wells vary from 1200 to 2000 feet in depth. Water is drawn only from below depths of about 600 feet. Its quality is generally fair being better toward the south end of the area than at the north end or in some areas of heavier draft. Available records do not enable the present ground water levels or the fluctuations under past use to be definitely determined. The ground water appears to slope from the valley trough toward the west under present conditions. The sources of ground water replenishment are uncertain; the supply must, of necessity, come from a relatively distant source. In other areas remote from sources of ground water supply, the ground water has been found to be sensitive to heavy draft. With only one-eighth of the area irrigated, lowering appears to be occurring. The conditions are favorable for an overdraft on the underground waters to develop. Owing to the depth of the wells required in this area, ground water development is necessarily expensive.

Tulare Lake Area.

There has been much activity in the installation of deep wells recently in the Tulare Lake area. In wells formerly artesian, water now stands thirty to sixty feet below the ground surface and pumping lifts, including the drawdown, exceed 100 feet. Gas usually occurs in the deeper water. The quality of the water from some wells is not as good as is desirable. However as the areas supplied will receive canal service in years of adequate stream flow and may be submerged at times when Tulare Lake fills, soil injury from the use of ground water is not considered probable. The source of supply of these deeper wells is outside the area of Tulare Lake. The source has not been definitely traced. The supply may come from more than one of the tributary streams. Owing to the distance of movement and fineness of the materials, these wells would be expected to be relatively sensitive to heavy draft.

Summary of Chapter IV.

GROUND WATER IN TULARE COUNTY AREAS.

The four streams in Tulare County in both the order of their size and of their location from north to south are the Kaweah and Tule rivers and Deer and White creeks. The ground water conditions for the areas dependent on each of these streams are discussed separately.

Kaweah River Areas.

The mean annual run-off of the Kaweah River is estimated to be 440,000 acre-feet. The total gross area considered to be dependent on the Kaweah River for such water supply as it may receive is 365,000 acres of which 175,000 acres are now irrigated. This represents an acre of crop for each 2.5 acre-feet of mean annual stream flow. Ground water records covering the larger part of the area are available since 1917. Records were begun in the remaining area in 1920.

For the eight years from 1917 to 1925, the ground water over the whole Kaweah River area has lowered an average of 1.6 feet per year. The stream flow for this period has averaged 78,000 acre-feet per year below normal. For the gross area of 365,000 acres, the ground water lowering represents an amount of water about equal to the deficiency in stream flow. For the area as a whole the present development appears to require the full average supply. The development of any material part of the remaining half of the gross area which is not now irrigated would result in an overdraft on the supply. While as a whole present use appears to about equal the average water supply, the draft and use in the different parts of the area are not balanced. An excess canal supply is secured in some areas, in other areas pumping exceeds the average replenishment.

In the main area covered by canals diverting for lands below Venice Hills, the ground lowering in the five-year period from 1920 to 1925 has been less than five feet in the areas receiving canal service of regular character. The lowering in areas of irregular canal service has been about ten feet. In much of this area the ground water would be expected to rise closer to the surface than is desirable in years of normal stream flow. For the whole area the average lowering was about twelve feet from 1917 to 1925.

For the upper areas above Venice Hills, on the north side of the river, recent increases in pumping appear to have resulted in a draft in excess of the supply reaching the parts of the area more distant from direct canal use. On the south side of the river, in an area of 3000 acres of which four-fifths were developed, a lowering of fifteen feet occurred from 1920 to 1925. Although some canal service is secured the present rate of draft appears to exceed the present sources of supply and continued lowering is to be anticipated. For the whole area the irrigation of one-fourth of the gross area resulted in an average lowering of ten feet from 1917 to 1925.

There is a gross area of 20,000 acres of which 7300 acres are now irrigated west of the Lindsay-Strathmore Irrigation District toward which the ground water slopes from all directions due to the lowering of the ground water that has occurred under the heavy local draft. In the portion of this area toward which the ground water slopes from the main Kaweah River area the ground water lowered twenty feet from 1917 to 1925. The total lowering to date exceeds eighty feet in some parts of this area. The greatest lowering has occurred within five miles of areas along Outside Creek in which the lowering has been less than five feet during the deficient years from 1920 to 1925. The excessive lowering does not appear to have established ground water movement into the area to a sufficient extent to supply the present draft as the lowering was greater in 1925 than that in either 1918 or 1919 although the stream flow in 1925 was larger than that in either of the earlier years.

There is an area of 95,000 acres, of which 15,000 acres are irrigated from wells, that is within the general area of the lower Kaweah Delta but outside the area served by canals. The lowering that has occurred in this area is generally proportional to the amount of the local draft.

Little lowering has occurred even in the dry years where little pumping is practiced. Where much pumping has occurred a lowering of several feet per year is shown. The experience in this area is an additional illustration that ground water movements from distant sources occur relatively slowly and that areas in the direction of the ground water slope from direct sources of supply may be unable to support a pumping draft sufficient for the irrigation of more than a small part of the gross area. The irrigation of one-sixth of the gross area resulted in an average lowering of sixteen feet from 1917 to 1925.

Areas Dependent on Tule River.

The mean annual run-off of Tule River is estimated to be 132,000 acre-feet. About 68,000 acres are irrigated in the gross area of 204,000 acres whose water supply is dependent upon Tule River. This represents an acre irrigated for each two acre-feet of mean annual run-off. For the five years 1921 to 1925 the average stream flow has been 90,000 acre-feet per year. The average lowering has been 11.5 feet for the same period. For the whole area the ground water storage represented by this lowering would be larger than the shortage in stream flow in these years indicating some overdraft for the area as a whole. As in the case of other delta areas, the conditions vary in the different parts of the Tule River Delta.

The main area of the Tule River Delta includes the lands receiving canal service. It represents the lands sufficiently near Tule River and its canals to have more definite sources of water supply. Of the total area of 77,000 acres about one-third is irrigated. The ground water lowering from 1921 to 1925 has averaged five feet in the part of the area having the heaviest pumping draft but also receiving the largest canal supply. The middle portion of the area lowered ten feet with a slightly smaller draft. The outer portion lowered twelve feet under a much lighter pumping draft. These results indicate the need for direct sources of supply within each area if much pumping draft is to be maintained.

There is an area north of the Tule River Delta toward which the ground water now slopes from the Tule River Delta. Of the gross area of 24,000 acres nearly one-half is now irrigated from wells. The present ground water slope is the result of the excessive lowering that has occurred in this area. The lowering in 1925 was larger than that in earlier years of similar stream flow. A general average ground water lowering of about four feet per year can be expected in this area.

On the south of the main Tule River area are 7000 acres of which one-eighth is now irrigated. An average lowering of eight feet has occurred in the last five years. This is less than the average lowering in other outer Tule River areas. Any larger draft would be expected to result in an increased rate of lowering.

On the outer part of the Tule River Delta is an area of 97,000 acres of which one-fourth is irrigated from wells. An average rate of draft of about one-half acre-foot per acre of gross area resulted in a lowering of about twelve feet from 1921 to 1925. In the upper part of this area in 1921 the draft was similar to that in the part of the main area receiving canal service; the ground water lowering was six times as large as in the canal area. This comparison illustrates the greater sensitiveness to draft of such outer areas that do not have direct local sources of ground water supply. An average ground water lowering of about two feet per year is to be expected in this outer area as a whole under existing conditions of use. Larger amounts of lowering are to be expected in areas where more than one-third of the gross area is supplied by pumping from wells.

Deer Creek Area.

The estimated mean annual run-off of Deer Creek is 19,000 acre-feet. This is the only source of supply for a gross area of 106,000 acres of which 19,000 acres or eighteen per cent are now irrigated. These figures include the area in the Terra Bella Irrigation District. The ground water records indicate that even this small proportion of development will result in an average ground water lowering of about 2.5 feet per year. The present pumping draft is about twice the mean annual flow of Deer Creek.

White Creek Area.

The estimated mean annual run-off of White Creek is 6300 acre-feet. An area of 104,000 acres in the southern part of Tulare County is dependent on White Creek for such ground water supplies as it may receive. About one-fifth of this area is now irrigated from wells. From 1921 to 1925 the ground water has lowered an average of twelve feet, the lowering being as large as thirty feet in areas of concentrated draft. The total pumping draft in 1925 was eight times the estimated mean annual run-off of White Creek. Further increase in area irrigated by pumping from wells in this area can only increase the present rate of ground water lowering.

Summary of Chapter V.

GROUND WATER IN KERN COUNTY AREAS.

The irrigated areas of Kern County include a wide variety of conditions of supply and draft. Kern River has an average annual run-off of about 800,000 acre-feet per year. The areas receiving the larger amounts of canal service practice very little pumping. Canal use has resulted in the need for drainage in much of such areas. Other areas are distant from active sources of ground water supply and show ground water depletion under present conditions of use. The conditions can be more readily discussed by separate areas.

Areas Above the East Side Canal.

This area lies south and east of Bakersfield in the vicinity of Arvin. The run-off of Caliente Creek is considered to be the only source of ground water supply for this area. This run-off is estimated to be an average of 35,000 acre-feet per year. Of the gross area of 55,000 acres about 17,000 acres are now irrigated from wells. The present pumping draft for the thirty per cent of the total area that is irrigated appears to be fully equal to the available supply. A maximum ground water lowering of twenty feet has occurred in the years 1920 to 1925 in the area of heaviest pumping draft. An increase in the area irrigated can only be expected to result in an increase in the rate of ground water lowering.

Area Under East Side Canal.

This area includes 33,500 acres of which about one-half is irrigated. A larger area is supplied entirely from wells than the area receiving canal service. The available records indicate that the present area irrigated is as large as the present sources of water supply can support without progressive gound water lowering.

Main Canal Area South of Kern River.

This area includes 162,000 acres of which about one-half is in the Kern River Water Storage District. Past canal use has resulted in a relatively high ground water table over much of the area so that drainage is needed. Owing to the character of the canal supply obtained there has been little development of pumping. A continuation of the past amounts of canal diversion into this area can be expected to maintain a high ground water. Present average rates of diversion exceed crop consumption of moisture and drainage is essential on much of this area if adequate crop production is to be secured. The physical conditions for pumping are favorable on much of the area near Kern River. Such pumping, in addition to furnishing relief as drainage, would also make available additional water supply.

Rosedale Area.

This area lies adjacent to and north of Kern River. Of the gross area of 44,000 acres about 12,000 acres were irrigated in 1925. About one-third of the irrigated area secures its supply entirely by pumping. Ground water in this area is relatively close to the ground surface. The canal supply has exceeded the crop use in the past and excess evaporation from moist areas and outward ground water movement have occurred. The ground water lowering that resulted from the shortage in canal supplies in 1924 has caused a reduction in the ground water losses from this area. Apparently canal delivery into this area can be decreased without shortage in the crop supply if the ground water is held at the levels of 1924 and 1925.

Shafter, Wasco and McFarland Area.

This area extends from the Rosedale area on the south to the north as far as canals from Kern River or Poso Creek affect the ground water conditions. It extends from the Lerdo Canal on the east to the western edge of general pumping above the valley trough area. The gross area is 181,000 acres. The area now irrigated by pumping is 45,000 acres. The area irrigated from canals varies with the available canal supply from a small acreage to 20,000 acres or more in years of large stream flow.

Prior to canal construction the ground water stood about fifty feet below present levels. The only sources of supply were Poso Creek and such very limited ground water movement as may have occurred from the foothill areas to the east. Seepage from Kern River does not reach this area. Pumping has been extensively developed near Shafter, Wasco and McFarland. The ground water secured is mainly that resulting from percolation losses from the canal use on the higher lands. Outward movement of ground water probably occurs to areas to the west.

An analysis of the available records indicates that the consumptive use of moisture is about 2.0 acre-feet per acre of cropped area and that the outward ground water movement may amount to 25,000 acre-feet per year. These results when applied to the present areas irrigated represent a total requirement in excess of the average supplies now received. With present development and average water supply conditions a ground water lowering of about 1.5 feet per year would be expected.

Studies of available sources of additional canal supply for this area are being made by the Kern River Water Storage District. The preceding conclusions are based on the present conditions of canal delivery.

Northern Kern County Area.

The effect of Kern River Canals and Poso Creek does not extend to the northern boundary of Kern County. The only source of supply for the remaining area is Rag Gulch whose erratic run-off has been estimated as an average of 3500 acre-feet per year. The pumping draft in 1921 was estimated as 9000 acre-feet. This has increased since 1921. Ground water records are not complete in this area but lowering has occurred and can only be expected to continue under existing conditions.

Lower Areas in Kern County.

These areas represent lands along the lower course of Kern River mainly in the valley trough.

The Pioneer Canal area receives canal irrigation. Some pumping is developed but additional draft appears feasible.

In the Goose Lake Slough area about 5000 acres are irrigated, largely from artesian flow. No present overdraft is apparent in this area.

In the Button Willow area there is little ground water development. Deep wells flow sufficiently for stock use. Toward the north some wells encounter water of poor quality. A few wells of good yield have been secured recently at the south end of the area. The generally fine texture of the water bearing materials makes it difficult to secure good yields in parts of the area.

There is not much pumping for agricultural uses in the area south of Tulare Lake. Some deep wells are in successful use. There has been activity in pumping for duck club use in parts of this area in recent years.

CHAPTER II.

GENERAL DESCRIPTION OF SOUTHERN SAN JOAQUIN VALLEY.

This report presents the results of a study of the ground water resources of the southern half of the San Joaquin Valley extending from the southern end to and including the Kings River area. The rapid increase in the use of ground water for irrigation in this territory in recent years, with the resulting lowering of the elevation of the ground water in many parts of the area, makes the study of these conditions an important part of the State's water resources investigation. Should these waters continue to recede, extensive areas of intensively cultivated land dependent upon irrigation will be without a water supply.

Ground waters, like surface water supplies, must have a source, the volume of which limits the amount of draft that can be permanently supplied. The measurement of the volume of surface water supplies has been a recognized field of endeavor for over twenty years. Development of these supplies has been based on the knowledge so obtained. Similar records of ground water supplies have been attempted only in recent years although there is the same need for making available information regarding the extent of ground water supplies that there is for surface streams. The physical conditions involved increase the difficulty of determining the extent of ground water supplies. Such difficulty, however, does not remove the need for such information but rather increases it, for without such information not even approximations to the supply can be made.

The serious nature of the problems now confronting several large sections of the area, and the dropping ground water level paralleling the complete utilization of local supplies, has made it desirable to assemble all the information possible. The great volume of data collected for this report strongly support the deductions concerning the present condition of this supply and the great danger confronting these communities unless cognizance is taken of these conditions so that remedial measures may be undertaken.

DATA AVAILABLE ON GROUND WATER.

The State Department of Engineering undertook active studies of ground water conditions in parts of this area in 1920. Prior to this, some general studies had been made by the U. S. Geological Survey, the results of which are reported in Water Supply Papers 222 and 398. In 1920, in cooperation with Kern and Tulare counties and other interests, studies of the local water resources, both surface and underground, were begun in these two counties. The results of these investigations were published for Kern County in Bulletin No. 9 of the State Department of Engineering, and for Tulare County in Bulletin No. 3 of the Division of Engineering and Irrigation; the reorganization of the State's Engineering Department having resulted in the change in name. Beginning in 1921, observations of the fluctuation of the ground water within their own areas were undertaken by several of the irrigation units on Kings River. With the filing of the petition for the organization of the Kings River Water Conservation District in 1924, these records have been before the department in its investigations of this district.

Following the completion of the investigations on which bulletins 9 and 3 mentioned above were based, ground water records have been continued in both Kern and Tulare counties by local interests. In Kern County the Kern River Water Storage District has maintained quite complete records since its organization. Observations have also been made by the Kern County Land Company. Supplemental records were secured by the Division of Engineering and Irrigation in Tulare County in the fall of 1922 and 1924.

In the Kings River area the available records up to the fall of 1925 consist of the observations made by the individual irrigation districts and other forms of organization. These are of varying extent as to both the period covered and the completeness and detail of the observations.

Beginning in August, 1925, funds have been made available jointly by the Division of Engineering and Irrigation and of Water Rights for the field and office work in collecting and recording observations being made by all of these organizations and for the making of direct observations in areas for which records were not being obtained. This work has been under the direction of Mr. C. L. Kaupke, watermaster on Kings River.

Through these various agencies records are now being secured on the ground water fluctuations over practically all of the area of the San Joaquin Valley from the Kings River area south. All of these records have been made available for the preparation of this report. The context of this report is based on the records of about 800 wells in the Kings River areas, 800 wells in the Tulare County areas, and 700 wells in Kern County.

MAPS DELINEATING GROUND WATER CONDITIONS.

In the discusion of the ground water conditions for any large area some features can be discussed for the entire area, others are local in character and require discussion by localities. In order to avoid repetition, the general features are discussed for the area as a whole, followed by the detail discussion of the data pertaining to the local areas. The elevation of the ground water, its depth below the ground surface and the drop in the water plane during the last five years have been delineated on maps of the southern San Joaquin Valley. These maps are in the pocket at the end of this report.

Ground Water Contour Map.

Map No. 1 shows ground water contours that indicate the elevation of the water table over the entire area. The location and number of all wells to which reference is made in the text and on the plates is shown on this map. Other wells for which data is available which were used in preparing the maps and in determining ground water fluctuations are shown without numbers on the map. The number and location of such wells shows the extent and thoroughness with which the ground water observations have covered the different areas.

The elevations on the ground water contours are the heights above sea level datum. The ground water contours join points at which the ground water stood at the same elevation. They have a similar usefulness in showing the location and slope of the ground water table as surface contours have in showing the ground surface. The ground water elevations of October, 1925, were used as the basis for Map No. 1, as this represents recent conditions at the season of the year when fluctuations were occurring at a minimum rate. Observations are also more completely available over the whole area for 1925 than for earlier years.

Ground water movement occurs mainly along the direction of the steepest ground water slopes. Such steepest slopes are at right angles to the direction of the contours. Map No. 1 shows many features of interest regarding the ground water in this area.

The division of the ground water slope at the divide of Kings River near Summit Lake is shown by the ground water contours. The drainage of the ground water toward the San Joaquin River in the area north of Fresno is also shown by the direction of the slope. Sufficient data was not avilable from which to plot the ground water contours west of Fresno Slough and the contours in this area are not shown. The ground water slope toward Tulare Lake from the north and east is shown. A similar slope from the south and west would probably be shown if sufficient well records on which to base contours in these areas were available.

The effect of pumping in the vicinity of Lindsay is shown on Map No. 1. Prior to pumping the ground water sloped from the east toward the west as in other areas adjacent to the valley edge. The lowering in this area has created a cone of depression into which the ground water slopes from all directions. This reverses the natural direction of the ground water slope on the west of this area.

Map No. 1 also shows why the ground water in the different parts of the area depends on the local sources of supply rather than on any general or mingled sources. The ground water on the Kaweah Delta has an elevation of 400 feet at the upper point of the delta; its elevation is only 200 feet at the outer and lower edge of the delta. The main area of the Kaweah Delta is above the ground water in the valley trough and can not be affected by the lower ground water in the valley trough. Ground water along the general east side of the valley has a slope of about ten feet per mile toward the valley trough. There is very little cross slope from the ground water in one stream area toward adjacent stream areas.

In Kern County a ground water depression in the area above the East Side Canal southeast of Bakersfield has been caused in recent years by the pumping in this area. The flatter slope of the ground water above the canal than that below the canal indicates the effect of the canal on the adjacent ground water.

Depth to Ground Water Map.

Map No. 2 shows the depth to ground water for the parts of the area for which data is available. The depths shown represent the distance from the ground surface to the ground water when the pumps are idle. When pumping the ground water in the wells lowers by an amount necessary to cause the flow of water into the well. This lowering while pumping is usually called the drawdown. The actual pumping lifts in any area will exceed the depths shown on Map No. 2 by the amount of such drawdown. For usual conditions in this area the drawdown is from ten to twenty feet. Where tight materials are heavily pumped the drawdown may be forty to fifty feet.

In the areas receiving adequate canal service the ground water is generally less than twenty feet below the ground surface. In many areas it is within ten feet. Until the dry year of 1924 and the recent increase in supplemental pumping it was less than five feet in some areas.

The depth to ground water increases generally in the areas away from canals and streams. It is greater near the eastern edge of the valley where the depth exceeds 100 feet in many areas. In some cases depths as large as 200 feet are found.

The effect of ground water lowering due to heavy draft is shown in some areas. This is illustrated in the area west of Tulare and near Tipton and Earlimart.

Depth to ground water in much of the valley trough area is not shown on Map No. 2. Most of this area was formerly artesian and wells flowed. Recent pumping has resulted in the loss of the artesian pressure and the water in the wells usually stands below the ground surface. However, the depth to water fluctuates during the season and can not be adequately shown on a map representing depths at a selected date.

Map Showing Ground Water Lowering.

Map No. 3 shows the ground water lowering from the fall of 1920 to the fall of 1925 for those parts of the southern San Joaquin Valley for which the data is available. In the Kings River area observations were not begun until 1921 or later in the different parts of the area. In the main canal areas on Kings River the lowering has been less than ten feet and in most of these areas less than five feet for the last four years. Most of this lowering occurred in 1924. In some outlying areas larger amounts of lowering have occurred.

Map No. 3 shows the lowering in the main pumping areas in Tulare County. The lowering has exceeded twenty feet in areas distant from direct sources of supply in which heavy pumping is practiced. The conditions resulting in such lowering are discussed in detail for each area in Chapter IV. In a few areas no lowering occurred. Lines of no fluctuation for 1922 and 1925 are also shown. Within these areas no lowering occurred in these years. In 1922 the stream flow was somewhat above normal and in 1925 somewhat below.

In Kern County a lowering of as much as thirty feet occurred in some of the Wasco and Shafter area for these years. Less than five feet lowering occurred in the main canal-served areas. Above the East Side Canal the ground water lowered as much as twenty feet in the areas of heaviest pumping.

GENERAL GROUND WATER CONDITIONS.

In general the ground water conditions throughout most of the southern San Joaquin Valley are relatively favorable for the securing of adequate yields from wells of moderate depths. Within the main delta areas of the larger streams, wells of less than 200 feet depth will usually yield discharges of one second-foot or more with drawdowns of less than twenty feet. Such plants have generally used centrifugal pumps set in shallow pits. Many such wells are less than seventy-five feet deep.

In areas more distant from the streams where the materials are generally finer in texture the water stands deeper and deeper wells are required to secure adequate yields. Even in such areas wells of less than 200 feet deep were formerly frequently used. Present practice tends toward wells of greater depth equipped with deep well turbines. Larger diameter wells are used and generally larger discharges secured than from the shallow wells. Such wells generally vary from 300 to 500 feet deep.

In some parts of the area such as the valley trough and west side there is little available ground water in the surface materials and even deeper wells are required. These wells may vary from 600 to 2000 feet in depth in different areas. The water stands much closer to the ground surface in these wells than the depths at which it is encountered. Many of the deep wells formerly flowed. Such deep plants cost from $8,000 to $20,000 to install and equip. In order to reduce the cost of the water secured they are usually operated nearly continuously, enough land being served in different crops to utilize the discharge throughout most of the year.

Very few dry holes are encountered in drilling in any part of the southern San Joaquin Valley. The valley fill varies in the coarseness of its texture but wells in almost all parts of the area will encounter water bearing strata at some depth. Usual well logs consist of alternating strata of sands and clays. The clay or sand strata in adjacent wells frequently occur at different depths indicating that the materials have been deposited under irregular conditions such as those now in effect along the present surface streams.

GROUND WATER AS A SOURCE OF IRRIGATION SUPPLY.

The cost of water secured by pumping is usually larger than the cost of water delivered by the canal systems in this area. Where canal service is available it is generally used in preference to dependence on pumping. However, canal service in the southern San Joaquin Valley is dependent on the direct flow of the streams, no storage for irrigation having as yet been constructed on the tributary streams. In order to utilize the unregulated stream flow as fully as is feasible, canals have been constructed which are able to secure stream flow only during relatively short diversion seasons. The service under such canals is usually in excess of crop needs during the diversion period in order to build up the ground water for use in the later seasons. In many areas the diversions have brought the ground water sufficiently close to the surface so that subirrigation occurs.

In recent years the change toward crops of higher return and greater sensitiveness to shortage in supply has led to the installation of many pumping plants to supplement the water secured from canals. Development of this character has been more extensive in the last three or four years than that based on pumping for the entire supply.

Ground water has advantages over canal supplies which may tend to partly balance its increased cost. Each owner is independent in his times of operation and is not subject to delivery schedules such as are a necessity under canal service. If the stream secured from the well is sufficiently large to furnish an adequate irrigation head, the times of irrigation can be adjusted more closely to the crop needs than is always possible under a canal. Most wells in this area furnish an adequate stream for furrow irrigation.

In many parts of the southern San Joaquin Valley ground water is the only source of supply available. The rate of the development has varied with the prospective crop returns. In periods of anticipated high crop returns many new plants have usually been installed. When the expected crop returns have not been realized, the anticipated profits have been reduced or have disappeared. A pumping plant in most parts of this area requires several years use to return its cost.

CLIMATE.

The climatic conditions in the southern San Joaquin Valley are favorable for the production of a wide diversity of crops. Temperature conditions are favorable generally. Citrus crops prosper on the higher levels along the margins of the valley. Crops generally grown are deciduous orchards, vineyards, alfalfa, cotton, grain and truck.

The mean annual rainfall in the area varies from about 5 inches in the southern end to about 10 inches in the north. This occurs mainly during the winter months and is inadequate to furnish sufficient moisture for crops. The agricultural production of the entire area is almost wholly dependent on irrigation.

SOILS.

As in any large area, much variation in soils occurs. Considered as a whole, the soils are good; for much of the areas the soils are of good texture and depth, free from alkali and suited to a wide variety of crops. Some lands are underlain at small depths with hardpan which affects moisture movement. Other areas are alkaline, some from natural causes and others from the results of irrigation. The results of surveys by the U. S. Bureau of Soils have been published and are now available over the whole area.

WATER SUPPLY.

The only sources of ground water supply entering this area as a whole are the surface run-off of the tributary streams and rain falling on the overlying ground surface. The amount of rainfall is so small that it can be of only very limited, if any, aid as a direct source of ground water on the valley area. It is only in areas of high ground water that any moisture may reach the ground water from the direct penetration of the 5 to 10 inches of mean annual rainfall.

In the adjacent foothills are areas receiving larger, but still small, precipitation where, due to the rougher topography, some local run-off occurs which is absorbed before it reaches definite channels. However, even in these areas the rainfall is relatively light, not exceeding 15 to perhaps 20 inches. Any absorption from such amounts of rainfall would be very limited. It is very doubtful if more than a very small percentage of the rainfall on such areas penetrates below the reach of plant roots. Rainfall is not regarded as a source of any material amount of ground water for the area as a whole.

The main source of water supply for the southern San Joaquin Valley consists of the surface run-off of the streams draining the higher adjacent mountain areas. Such mountain areas are mainly granitic and no appreciable amount of absorption or of outward ground water movement can be expected. As the stream gaging stations are located within the areas of the older formations, they are above areas where loss from the stream channel would occur. The measured stream flow can be used with assurance that it represents all of the water supply from its drainage area above the points of measurement. Such stream flow records are available for all of the main streams. There are a number of smaller and lower drainage areas for which only partial or no records are available. Various estimates of the average run-off of these areas have been made.

Estimates based on the period of actual records on the measured streams and on estimates for those not measured were prepared in connection with bulletins 9 and 3 previously mentioned and in the investigations of the proposed Kings River Water Conservation District. These estimates have been extended to include the measured run-off for several more years. The inclusion of the records for the years since bulletins 9 and 3 were prepared results in a reduction in the average run-off based on the earlier records due to the deficient run-off of recent years. The results are as follows:

Estimated Total Mean Annual Run-off from Drainage Basins Tributary to the Southern San Joaquin Valley Based on Period of Direct Measurements.

Drainage Basin	*Estimated run-off, acre-feet, mean seasonal*	*Period of measurement*
West Side Streams	10,000	
Streams South of Caliente Creek	28,200	
Caliente Creek	35,400	
Kern River	751,000	1893–1925
Poso Creek	20,000	1920–1925
Other Small Areas North of Caliente Creek	11,300	
Rag Gulch	3,500	
White Creek	6,300	
Fountain Springs	1,000	
Deer Creek	18,900	1919–1925
Tule River	132,000	1901–1925
Frazier Valley	500	
Lewis Creek	1,500	
Yokohl Creek	4,000	
Kaweah River	440,000	1903–1925
Cottonwood Creek	7,000	
Cottonwood Creek to Kings River	7,700	
Kings River	1,803,000	1895–1925
Areas North of Kings River	7,700	
Total	3,289,000	

USE OF SURFACE WATER SUPPLY.

At the present time nearly all the tributary run-off of surface streams is utilized for irrigation; however, some loss occurs by outflow through Fresno Slough, the only channel leading away from the southern San Joaquin Valley, or by evaporation from low areas in which surplus flow accumulates or is stored. Kings River is the only stream that contributes to Fresno Slough. Under the recently existing conditions, the average annual amount of outflow from Kings River through Fresno Slough is estimated to have been about 350,000 acre-feet. This varies from practically nothing in years of small run-off to large amounts in years of excessive rainfall.

A portion of the run-off of Kings River and the surplus run-off of Kern, Tule and Kaweah rivers collects in Tulare Lake. In past times, Tulare Lake has varied from dryness to a stage that would produce overflow to the north. At present the lake bed is largely reclaimed, the decrease in inflow due to diversions for irrigation making this possible. However, in years of surplus run-off, water in excess of that which can be used will collect in Tulare Lake. Much of this can be pumped out for use but owing to the shallowness of storage, evaporation losses will be relatively large. Under existing conditions the evaporation loss from Tulare Lake may average about 100,000 acre-feet per annum.

There is also loss by evaporation in Buena Vista Lake, into which part of the Kern River empties. This lake is also broad and shallow. In excess years the spreading of the surplus flow on a wide area toward Tulare Lake results in an increased evaporation loss.

The total of all of these losses of water pertinent to present conditions of use is only about 15 per cent of the total mean annual run-off. Future increase in development based on the use of the local streams of the southern San Joaquin Valley must depend on improvements in practice rather than on the recovery of water now lost. Mountain storage would reduce the volume of the present losses but would not obviate all losses. Thus at the present time 85 per cent of the mean annual run-off of the streams is put to use and even with mountain storage much more can not be made available. This use of the existing supplies is probably more complete than that on any other large area in the state. Mountain storage will result in making possible a much better use of water than is now feasible without storage regulation.

AREAS IRRIGATED.

Lands of the southern San Joaquin Valley are irrigated by canals diverting water by gravity from the surface streams or from wells pumping from the underground waters. Some lands use both sources of supply. The area served by canals varies in different years with the volume of the stream flow. The area irrigated fluctuates most widely on those lands having water rights of later priority whose water supply is subject to wider variations from year to year. The area served by pumps does not vary with the annual run-off as does the canal-served areas.

The following table gives the areas which are irrigated in a year of normal run-off in the southern San Joaquin Valley at the present time.

These figures are based on data collected in the preparation of this report and other investigations of the Department of Public Works.

Area	*Usual area receiving canal service only, acres*	*Area receiving both canal and pump service, acres*	*Area receiving only pump service, acres*	*Total irrigated area, acres*
Kings River area	300,000	335,000	100,000	735,000
West Side area	------	------	30,000	30,000
Tulare County areas	80,000	65,000	170,000	315,000
Kern County areas	190,000	10,000	90,000	290,000
Totals	570,000	410,000	390,000	1,370,000

The area now receiving only pump service is over 2½ times that irrigated from wells in 1912, as shown by comparison with the area irrigated from wells in the report of the Conservation Commission of that year.

These data show that a total area of 1,370,000 acres is now being irrigated in the southern San Joaquin Valley with a total mean annual run-off of 3,300,000 acre-feet. This is equivalent to the irrigation of an acre of crop for each 2.4 acre-feet of mean annual run-off. This represents a very complete adaptation of crop practice to existing conditions of run-off and an unusually complete development of the available supply. Complete utilization of the locally tributary stream flow could hardly result in the irrigation of over 1,650,000 acres or about one-half of the available irrigable area.

The latest census figures on areas irrigated are those for 1919. These are shown in the following tables. The figures given include small areas outside of the floor of the San Joaquin Valley.

Acreage Irrigated Classified by Streams, for 1919 and 1902, Taken from Table 7, Irrigation—California, Fourteenth Census of the United States.

Drainage Basin	*Area irrigated, acres 1919*	*1902*	*Per cent increase*	*Area included in enterprises 1920, acres*	*Area enterprises were capable of irrigating in 1920, acres*
Kern River	200,641	116,189	72.7	432,481	299,665
Tulare Lake	70,134	--------	----	204,860	147,444
Tule River	61,223	--------	----	175,777	109,412
Kaweah River	149,932	--------	----	356,703	299,474
Kings River	552,601	596,091	7.3	1,052,406	895,263
Totals	1,034,531	--------	----	2,222,227	1,751,258
Entire State	4,219,040	1,708,720	146.9	7,805,207	5,894,466

The acreage reported for each drainage basin in 1919 comprises all the irrigated land in that drainage basin, including that watered from springs and wells. The figures for 1902 are the only prior census in which the areas were segregated by drainage basins. The indicated decrease since 1902 on Kings River is due to difference in classification. There has been an actual increase in the area irrigated as well as an improvement in the character of crops on Kings River since 1902. The total area irrigated in 1919 was nearly one-fourth the total of the state. It is interesting to note that the increase in area irrigated between 1902 and 1919 has been much less than for the state as a whole because of the arrival at practically a complete utilization of the surface water supply in the southern San Joaquin Valley some time between these years.

Data regarding the use of ground water in 1919 are also given in the same report. The summary data are as follows:

Drainage Basin	Flowing wells Number	Flowing wells Capacity gallons per minute	Pumped wells Number	Pumped wells Capacity gallons per minute	Pumping plants Number	Pumping plants Engine capacity horse-power	Capacity of pumps gallons per minute	Average feet lift
Kern River	17	13,850	411	219,674	384	6,676	223,606	47
Tulare Lake	24	8,253	1,100	434,565	906	12,841	1,330,434	59
Tule River	2	251	1,146	493,272	974	11,329	995,319	45
Kaweah River	3	17	2,136	842,085	1,734	21,932	876,254	41
Kings River	34	10,000	2,517	1,183,710	2,283	25,426	1,225,607	23
Totals	60	32,371	7,370	3,173,306	6,281	78,204	4,651,220	--
Entire State	1,415	297,187	25,401	10,608,476	21,561	386,200	16,773,692	41

The southern San Joaquin Valley had pumping plants which represented about one-third of this class of development in the entire state. Similar figures for the present date would probably show even a larger proportion of the state's ground water development to be in this area.

VALUE OF AGRICULTURAL PRODUCTS.

Complete statistics are not available on the value of the products from this irrigated area. As the crops grown have a relatively high value per acre and as the production is generally equal to or above the average for such crops, the total value is large. Statistics collected by the Tulare County Board of Trade show an average crop value at the farm of the agricultural products of Tulare County of about $30,000,000 per year, or an average of nearly $100 per acre from all classes of crops. The irrigated areas in these counties are probably more productive than other large areas in the state and represent a very important and essential part of the state's agricultural resources.

GEOLOGY

The present surface of the southern San Joaquin Valley has been formed by the deposit of material brought into the valley by the tributary streams. The surface is divided by a ridge extending across the valley formed by the material deposited by Kings River. The amount of this material has been sufficient so that this ridge extends across the valley to meet the slope from the mountains to the west. The elevations on the ridge are higher than those in the Tulare Lake Basin to the south. The other streams have made similar but less extensive deposits. Kern River has built a small ridge across the valley. Kern and Buena Vista lakes lying in the trough of the valley in the course of the Kern River formerly received part of the run-off of Kern River. Buena Vista Lake is now used as a reservoir, an embankment having been built along its eastern side. This embankment has resulted in the reclamation of Kern Lake. Tule and Kaweah rivers have not a sufficiently large flow to have deposited deltas extending across the valley.

The total depth of the valley fill is not known; borings to depths of over 5000 feet have not encountered bed rock. This fill has been deposited in past geologic times, partly when the valley was submerged and partly under conditions similar to those at present. The material varies in texture from gravels and cobbles near the point at which the streams debouch from their canyons and along their channels to relatively fine and impervious clays deposited in areas remote from the stream channels or under conditions of submergence. These circumstances result in the ground water occurring under different conditions of pressure at various depths. Artesian wells were formerly obtainable over a larger part of the lower valley floor.

From Porterville north, the valley fill lies against the "Bedrock" series on the east. From Deer Creek south to the southern end of the valley there is an area of Tertiary sediments between the recent valley fill and the granites. The formations in the west are more irregular, consisting of shales, sandstones and conglomerates.

The following general description of the geology of the valley is quoted from Water Supply Paper 398 of the U. S. Geological Survey:

"The valley as a whole is a great structural trough and appears to have been such a basin since well back in Tertiary time. Since it assumed its general trough-like form, gradual subsidence, perhaps interruption by periods of uplift, has continued and has been accompanied by deposition alternating at least along what is now its western border with intervals of erosion. This interrupted but on the whole continuous deposition seems to have been marine during the early and middle Tertiary; but during the later Tertiary and Pleistocene, when presumably the valley had been at least roughly outlined by the growth of the Coast Ranges, fresh-water and terrestrial conditions became more and more predominant, until the relations of land and sea, of rivers and lakes, of coast line and interior, of mountain and valley, as they exist now, were gradually evolved. As these conditions developed, the ancestors of the present rivers probably brought to the salt and fresh water bodies that occupied the present site of the valley and its borders, or, in the latest phases of the development, to the land surface itself, the clays, sands, gravels, and alluvium that subsequently consolidated into the shales, sandstones, and conglomerates of the late Tertiary and Pleistocene series, just as the present rivers are supplying the alluvium that is even now accumulating over the valley floor.

"The very latest of these accumulations are the sand and silt and gravel beds penetrated by the driller in his explorations for water throughout the valley. They are like the early folded sandstones, shales, and conglomerates exposed along the flanks of the valley, except that they are generally finer, and are not yet consolidated or disturbed. The greater part, perhaps all of them, accumulated as stream wash on the valley surface or in interior lakes like the present Tulare Lake, but a proportion of the older sediment that is greater as we delve farther back into the geologic past accumulated in the sea or in salt bays having free connections with the sea. It is these very latest geologic deposits, saturated below the ground water level by the fresh water supplied chiefly by the Sierra streams, that constitute the reservoirs drawn upon by the wells, whether flowing or pumped, throughout the valley.

"The chemical composition of the ground waters, as well as their occurrence and accessibility, is related to the geology. Where the valley alluvium is derived from the Cretaceous and Tertiary beds of the coast ranges, rich in gypsum and other readily soluble minerals, the ground waters contain large quantities of the salts. Where, on the other hand, the alluvium is derived from the granites and metamorphic rocks of the Sierra, whose potassium, sodium, and calcium compounds are in the form of difficultly soluble silicates, the ground waters under ordinary conditions contain very little of these salts.''

The Kings River ridge is considered to separate the ground water of the San Joaquin Valley into two areas, that to the south being, practically, if not entirely, a closed basin. The ground water contours on Map No. 1 show a similar ridge or division in the ground water to that of the ground surface. The same nature of direction of slope of the pressure levels of artesian wells is also indicated by the available data. While available records do not indicate the pressure levels from wells sufficiently deep to represent the full valley cross section, those from all depths from which the ground water has as yet been used indicate a similar character and direction of the ground water slope. It appears logical to assume that any outward northward ground water movement from the area south of the Kings River ridge that may occur is of such small amount that it may be neglected in a consideration of the ground water supply and that the area under discussion in this report is for practical purposes a closed basin.

QUALITY OF GROUND WATERS.

Over much the larger portion of the southern San Joaquin Valley the quality of the ground water is good. For waters secured from the formations derived from the Coast Range or from the older materials on the east side, the quality is variable. In some areas waters vary in quality at different depths. A detailed discussion of the quality of the ground waters is included in Water Supply Paper 398 of the U. S. Geological Survey based on analyses made in 1910. Analyses were made in Kern County in 1920 in connection with the investigations of the Division of Engineering and Irrigation. Results of analyses made by private investigations have also been available. In order to supplement available data and make them more complete, about 30 samples, mainly from deep wells in the valley trough and west side areas, were analyzed in the preparation of this report.

Almost without exception waters from the recent valley fill on the east side of the valley are of good quality. These materials are derived from the granites and schists of the Sierras. The surface run-off from these same areas is relatively free from mineral constituents. Occasionally water from a shallow well in an area of alkali concentration may show high alkali content; in general east side waters from all depths can be used for irrigation without concern regarding their quality. In the southern portion, however, the older Tertiary formations extend into the valley sufficiently far so that some wells receive their supply through such materials. This water contains more impurities and sometimes is not suitable for irrigation. These waters are characteristically high in calcium sulfate or gypsum. Water containing a larger amount of such salts can be used without harm than waters containing the sodium salts. However, in some instances harmful results occur from irrigation with these waters. In the area east of

Bakersfield along the Mesa where such waters are encountered, it has been found that the quality of the water is improved if the upper strata are shut off.

Conditions are more variable in the valley trough and west side area than on the east side. In Water Supply Paper 398 the axial and west side waters were distinguished as to quality, the west side waters being characteristically high in sulfates and the axial or trough waters, while lower in sulfates, were higher in bicarbonates and chlorides. At the time of the field work (1910) on which this paper is based, deep wells were not available on the west side area north of Tulare Lake nor in the western part of Tulare Lake, so that the data apply to the shallow west side wells.

Deep wells are now in use on the west side area extending from Mendota to Tulare Lake. These wells range from 1200 to 1600 feet in depth in the northern portion of the area and increase to 1800 and 2000 feet in depth within the bed of Tulare Lake. The use of such wells is recent and adds to the data of Water Supply Paper 398.

In the area west of the valley trough, the waters from all deep wells sampled contained less sulfate than that found in the shallow wells. The amount of the sulfate was higher than in the axial or trough wells, which may indicate some mingling of water from different depths. The materials encountered at lower depths in such wells consist of granitic sands containing mica similar to that secured in east side wells. The character of the material and the quality of the water indicate that the water in these deeper wells may be derived from east side sources. These wells are perforated only below depths of 500 to 600 feet, indicating that the high sulfate water was probably considered to extend to that depth by the well drillers. That these conditions extend almost to the west edge of the valley is shown by a sample from a deep well on the Chaney Ranch in Sec. 5, T. 15 S., R. 13, which contained no more sulfate than wells near Mendota.

The waters from the northern part of the west side area contain amounts of sodium, bicarbonate and chloride which makes their continued use of doubtful value. Several wells have been in use for a number of years but no definite injury from the use of these waters has been observed. The samples collected show a larger amount of sodium chloride or common salt in the wells in the northern part of the area than in the southern. Samples from the southern half of the area, except from localities of heavy draft, showed water of suitable quality.

Water from deep wells in the northern and western portion of Tulare Lake showed a very low sulfate content, the sulfate being much lower than that in the deep wells in the west side area. The bicarbonate content was larger and the chloride similar to that of adjacent west side water. These waters are more nearly like those found in the valley trough along Fresno Slough than the west side waters. The alkali content of these waters is larger than is desirable; however, as they are used on lands that receive irrigation from surface sources in seasons of favorable run-off, probability of their injury is minimized.

Along Fresno Slough, deep wells are in use by both the James and Stinson Irrigation districts as a part of their water suply. Additional deep wells are also used by individuals. The water from these wells shows fairly large amounts of bicarbonate and chloride with little sulfate. The continued use of these waters alone as a source of supply would probably eventually result in soil injury. All use is, however, as a partial supply, other water being secured either from canals or from other wells.

South of Tulare Lake the waters from deep wells were found to be suitable for irrigation use, except in a portion of the lower and western part of the area. This area is marked out on Map No. 2 from the results of field investigations made under the direction of Mr. J. B. Lippincott in 1919. There is little use of ground water within the area of poor quality shown thereon.

CHAPTER III.

GROUND WATER IN KINGS RIVER AREA.

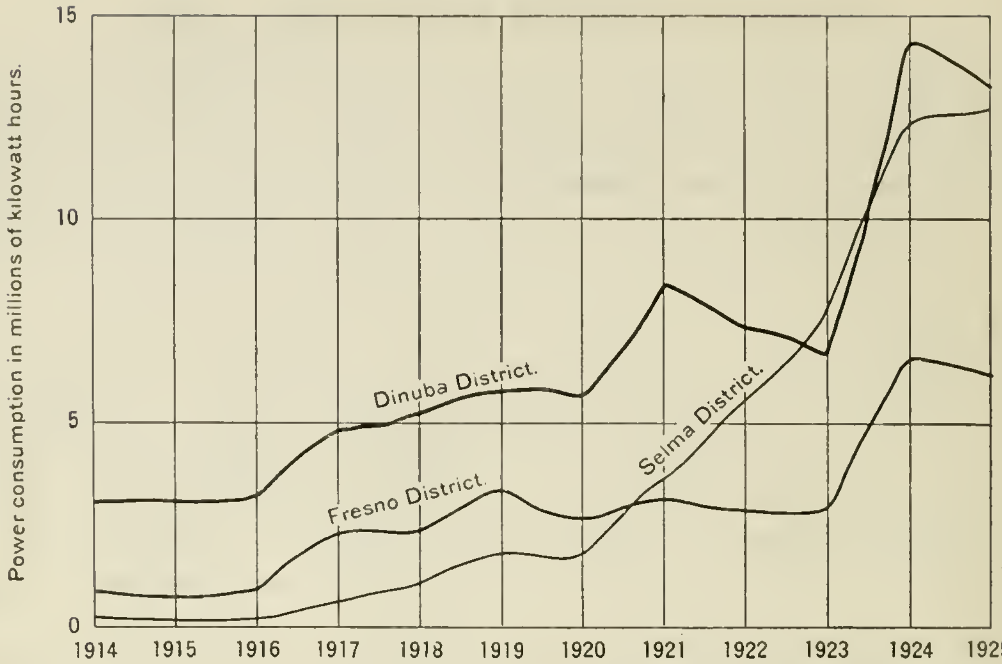
The Kings River area, as the term is here used, comprises those areas whose ground water is derived mainly or wholly from Kings River. The source of the ground water supply may be by percolation directly from the stream channels or by canal seepage and percolation from areas irrigated under the canal systems diverting from Kings River. The Kings River area extends on the north to the San Joaquin River and on the south to the Kaweah River areas and Tulare Lake. It is bounded on the east by the Sierra foothills. On the west it extends beyond the valley trough as far as pumping has been practiced. The boundaries are fairly definite except in the vicinity of Tulare Lake and west of the valley trough. Records of ground water fluctuation over this area are available for varying periods in the different parts. Detail records for the past four years are available in the Alta, Fresno and Consolidated districts. Less extensive records are available for the other parts. Also various scattered records have been secured in earlier years.

The ground water contours shown on Map No. 1 indicate the direction of slope of the ground water. The maximum movement of ground water is in the direction at right angles to the ground water contours. Map No. 1 shows that a rather narrow area at the north drains toward the San Joaquin River. In the upper portion of Kings River where the river occupies a deep channel Map No. 1 shows a slope toward the river channel from both sides. Westerly from Kingsburg the ground water contours show a change. The contours here show a slope away from the river as though the river were running on a ground water ridge. This indicates that in this section water percolates from the river channel and spreads outward into adjacent areas. Map No. 1 shows that this condition follows both channels of Kings River after it divides in the vicinity of Summit Lake. The ground water contours show a slope both to the north and to the south from this divide, similar to the slope of the ground surface.

For the purpose of discussing the available ground water, it may be considered that the Kings River area is a closed basin. The extent of any outward ground water movement is so small that for practical purposes the basin can be considered as closed. Outward movement to the west is improbable; the materials are rather fine, the slope flat and the Coast Range Mountains are in the way. Deeper ground water movement to the north has been discussed in Chapter I under Geology with the conclusion that it is either absent or very limited in amount. Some movement southward into the Tulare Lake area may occur but this is within the general basin area. Movement to the south of Tulare Lake does not occur as a reverse ground water slope from the south toward the lake is encountered. Therefore it is assumed that the supply and draft of the ground water in the Kings River area as a whole can be treated without allowance for material outward movement.

The ground water supply of the Kings River area is derived almost

Power consumed by agriculture.



Number of consumers of power by agriculture.

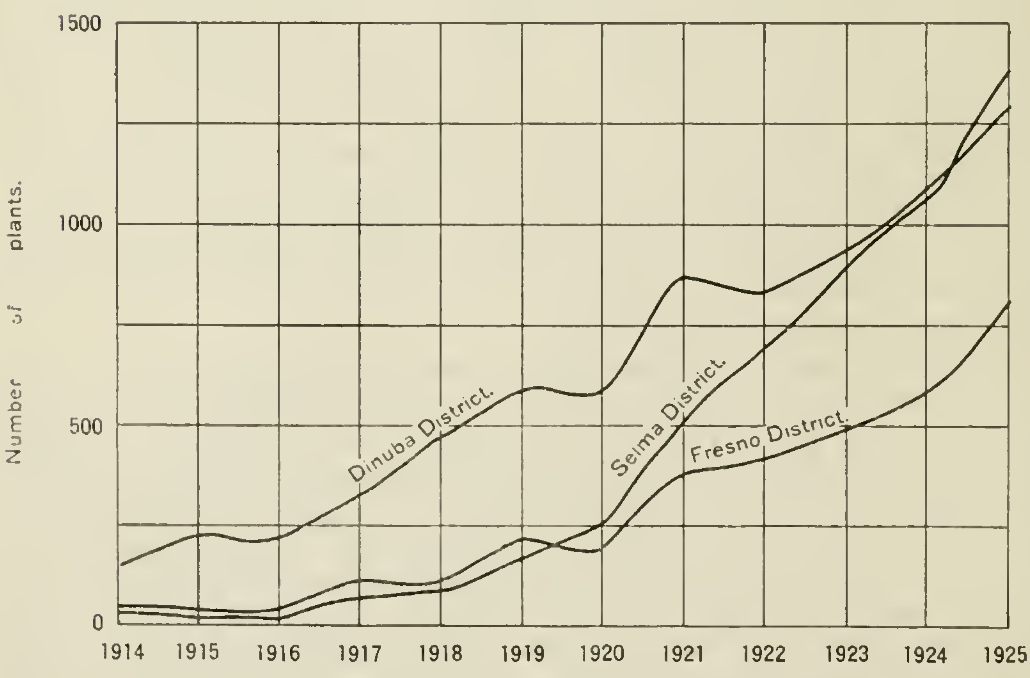


FIG. 1. Growth in use of power by agriculture for pumping in Dinuba, Fresno and Selma Districts of San Joaquin Light and Power Corporation.

entirely from the run-off of Kings River. The run-off of adjacent small drainage areas is included in the discussions but its amount is relatively very small. Additions to the ground water occur mainly through percolation after diversion for irrigation rather than by losses from the stream channel itself.

GROWTH OF PUMPING FROM GROUND WATER.

The increase in the use of ground water in the Kings River area has been very rapid in recent years. Such pumping constitutes the entire supply for about one-sixth of the area now irrigated and the partial supply for an additional two-fifths of the area. Nearly 60 per cent of the area irrigated receives some ground water supplies. Of the areas lying to the north of Kings River the Fresno Irrigation District has 30,500 acres whose irrigation is supplied entirely by pumping from the ground water. Much the larger part of the remaining 163,400 acres under canal service is equipped more or less completely with auxiliary well service. It is estimated that there are 3500 pumping plants in this district. In the Consolidated Irrigation District 44,000 acres are reported as receiving their entire irrigation supply by pumping from wells. The 81,500 acres additional which receive canal service are also largely supplied with supplemental pumping from wells. About 30 to 40 per cent of the areas in the Laguna and Riverdale Irrigation districts were provided with supplies secured by pumping in 1924. Many additional plants have been installed since 1924.

In the areas on the south side of the river, in the Alta Irrigation District nearly all of the 81,500 acres irrigated receives both canal and pump supplies. In the canal areas in Kings County little pumping has been practiced until recently; 75 plants were reported in 1925 in the Last Chance Canal area and 23 in the Lemoore Irrigation District.

In the lower areas, along the northerly channels of Kings River, pumping by canal organizations as well as by individuals is practiced. The Stinson and James Irrigation districts secure part of their supply by pumping from wells into their canals. To the south, there has been a rapid increase in pumping from deep wells in the northern part of Tulare Lake.

A good indication of the increase in pumping in the upper part of the Kings River area is furnished by the records of the San Joaquin Light and Power Corporation for its Dinuba, Selma and Fresno distribution districts which correspond approximately with the areas of the Alta, Consolidated and Fresno Irrigation districts. These records are summarized in Fig. 1 which shows the number of consumers of agricultural power and the power used by years. Development in the Alta District began somewhat earlier than that in the other two areas; pumping in the Consolidated District or Selma area although beginning later has increased more rapidly. Fig. 1 shows a larger proportional increase in power consumption in 1924 than in the number of consumers. This reflects the unusually long period of pumping in 1924 due to the small flow in Kings River. In 1925 the increase in number of consumers was sufficient to maintain nearly as large a power consumption as in 1924 although the canal supply was much greater.

Increases in the number of consumers in 1926 are reported to be larger than in the preceding years. These figures apply only to the consumers served by this company and do not include plants using other forms of power.

It is difficult to estimate the present draft on the ground water in the Kings River areas due to its variation from year to year. For the entire area there is probably a present gross draft of about 500,000 acre-feet per year. This is equivalent to nearly 30 per cent of the mean annual run-off of Kings River. The net draft on the ground water is less than this as some of the water pumped returns to the ground water by percolation from the areas irrigated. The availability of ground water in this area prevented serious crop injury in 1924 when the run-off of Kings River was the minimum that has been recorded. The ground water basins underlying this area thus serve as an excellent storage reservoir that fills during times of excess run-off and may be drawn upon heavily in times of shortage in surface supply. This condition is of very great value to the Kings River area and is largely responsible for the high character of the present irrigation development in much of the area.

METHODS OF ANALYSIS OF GROUND WATER CONDITIONS.

The conditions of canal and ground water use vary so widely in the different parts of the Kings River area that details must be discussed by sections. Because the replenishment to the ground water supplies comes largely from percolation from the canals and irrigated lands, the areas covered by the large canal systems represent fairly distinct ground water areas and the conditions of supply and use can be best discussed for the area covered by each of such large systems. For the smaller systems intermingling of ground water requires discussion by groups.

The general method of studying the ground water conditions in these areas has been the same. This consists in general in a comparison of the volume of ground water supply against the volume of its use with the resulting effect on the elevation of the ground water table.

The most important element of ground water supply is the diversions from Kings River brought into the area by canals. Losses to the ground water occur both by seepage from the distribution canals and by percolation from the lands irrigated. Additional supplies may come by ground water movement into the area from higher lands. The use of the ground water supply is measured by the draft by pumping from wells. The ground water may be depleted also by underground flow toward lower areas or drainage channels. The balance between the elements of supply and depletion will be reflected in the fluctuations in elevation of the ground water plane. When the elements of supply exceed the elements of use or depletion an accumulation of ground water will occur with a rise in the elevation of the water table. When the depletion exceeds the supply a lowering will result. Therefore the fluctuations record the balance between the supply and depletion. From these data conclusions can be reached as to the extent of draft that can be supported by the ground water supply without a continued or permanent lowering of the ground water table.

The use of ground water requires fluctuations in its elevation. A ground water supply represents a form of storage which must be accumulated in the soil at times of surplus so as to be available for use in times of need. Fluctuations in the elevation of the ground water are a normal process. A regular range of fluctuation indicates a definite source of supply. Several feet of lowering within a season does not necessarily indicate overdraft.

If, however, at similar periods during the season the ground water is progressively lower from year to year under conditions of average supply, draft in excess of the supply would be indicated. The ground water elevation at the same time in different years when compared to the conditions of supply and use for the same years furnishes a basis for estimating the draft which can be supported by the average supply.

The water delivered into a given area and the acreage of crops irrigated were obtained from the records of the canal systems for the years covered by the ground water records. The fluctuations of the ground water were obtained from the readings of the observation wells. Any ground water movement into or out of the area is relatively constant unless a wide fluctuation in the ground water elevation occurs. For several of the areas, ground water records for the years 1922 to date are available. This period includes the very dry season of 1924, the somewhat above normal season of 1922 and the somewhat below normal years of 1923 and 1925. These seasons give a relatively wide range of conditions of canal supply and ground water use. The analysis presented for the different areas represents directly only the conditions during the particular years of actual record. Should changes in the conditions occur in the future the resulting conclusions may require similar modification.

The fluctuation records of the observation wells show certain common characteristics. The ground water rises during the period of canal supply; it falls during the late summer months when canal supply is small and pumping heavy. In the fall when pumping becomes relatively small in amount, the rate of ground water lowering decreases. The water table may either lower or rise during the winter months dependent on local conditions of ground water movement and use.

In examining the ground water fluctuations it was found that December 1 represented the end of the period of use by pumping and the beginning of the winter season. In many areas the ground water starts to rise at about this date. These conditions continue until about March 1 of the following year when the decrease in rainfall and the increase in use results usually in a lowering of the ground water unless water is being delivered in the canals. For these reasons the year has been divided into two parts in the study of those areas for which complete records are available—the season of canal diversions and pumping for irrigation extending from March 1 to December 1 and the winter season from December 1 to March 1.

For the winter season the ground water fluctuations were found to have no consistent relationship to the amount of the canal diversion during the preceding season. The amount of the diversions during the summer affects the fluctuations during that period but has little effect on the fluctuations during the following winter. It was found that the winter fluctuations vary, usually consistently, with the amount of rainfall during the winter months. This relationship is considered to be indirect, as direct penetration of moisture from the rainfall to the ground water probably does not occur except perhaps to a limited extent at times of heavy precipitation in areas where the ground water is within a few feet of the ground surface. Other factors such as winter pumping and local run-off vary with the rainfall. In winters of small precipitation some pumping is practiced. In years of large rainfall such pumping is reduced and any locally tributary run-off is increased. The net effect of all factors results in the ground water fluctuating in proportion to the rainfall during these three winter months.

For purposes of discussion the Kings River area has been divided into several separate areas representing differences in conditions of canal diversion, extent of pumping or length of period covered by the ground water records. The available information regarding each area is presented with such tentative conclusions as the available data appears to warrant. It is considered that the available data furnished adequate support for the general conclusions presented. Additional records in the coming years will probably result in some modification of any detail numerical conclusions that might be reached at this time regarding the draft that can be supported in any area.

GROUND WATER IN THE FRESNO IRRIGATION DISTRICT.

This district includes an area of 240,664 acres, of which 163,377 acres are reported as served by canals and 30,384 acres as served exclusively by pumps. The canals serving this area were built over 50 years ago. The early priority of its water rights enables this district to secure a more dependable water supply than many other areas on Kings River. These conditions make the study of its ground water of particular interest as representing conditions of more complete water supply. The Fresno Irrigation District is served by two canals. The Fresno Canal served about two-thirds of the total area in the lower or western part of the district and the Gould and Enterprise canals the higher or eastern portion. The Fresno District began observations on about 100 wells in September, 1921, mainly under the Fresno Canal, and the Fresno City Water Corporation on about 25 wells, mainly under the Gould Canal, in November, 1923.

There are no irrigated areas above the Fresno District, so that it receives no ground water supplies from such sources. The locally tributary drainage area has only a limited run-off, estimated as an average of about 8000 acre-feet per year. Such run-off is very irregular in occurrence and is negligible in quantity in years of small rainfall. The amount estimated is only about 2 per cent of the average annual diversion of the Fresno District.

Prior to the construction of canals, ground water occurred at depths of about 60 feet. As a result of irrigation, the ground water rose until a considerable area, largely south of Fresno, became damaged by water logging and alkali so that farms formerly productive in vines and trees were useful only for bermuda or salt grass pasture. Evidences of such damage are still observable in this area.

Efforts toward drainage were made, and investigations and experiments conducted by various agencies. These earlier attempts were mainly with open ditch or tile drains for small areas. No attempt to drain the general area was made, although plans for such works were discussed.

In recent years pumping for irrigation has increased throughout the district to such an extent that much drainage has been provided indirectly. The result has been to control the ground water until at present drainage is not a serious problem in this district. The existing pumping, together with control of the canal diversions, is sufficient to control ground water conditions. Any material rise of the ground water with resulting water logging of land is not to be expected under existing conditions of water supply and a normal increase in irrigated area. Any local area in which such a rise may occur can be controlled by additional local pumping. While much of the practice regarding the control of the ground water by pumping will be subject to development and adjustment in the future, it is considered that existing experience fully justifies the conclusion that pumping can control the ground water and that the demands of pumping for irrigation will result in such control. Pumping for drainage only is not probable as all water pumped can be coordinated with the irrigation demand resulting in dual usefulness.

Pumping for irrigation has been very largely a development of the last ten years as shown in the previous discussion of the growth of pumping. The draft in 1923 appears to have been about three times as large as that in 1913; in 1924 the pumping was over twice as large as in 1923, due to the deficiency in canal supply. Most of the increase from 1914 to 1923 appears to have occurred prior to 1920. There may be some question as to whether the present draft has been in effect long enough to result in stabilized ground water conditions particularly in the outlying areas.

The conditions for securing water by pumping from wells are particularly favorable in practically all parts of the Fresno District. Discharges of from 1 to 2 second-feet can be secured from wells of less than 150 feet depth in the larger part of the area. Wells of greater depth recently installed by the district have produced 4 to 5 second-feet. The drawdowns under such rates of discharge are relatively less than those in areas of closer textured material so that the pumping lifts are relatively small.

Bulletin 217 of the Office of Experiment Stations, U. S. Department of Agriculture, described ground water conditions southwest of Fresno. The field work was done mainly from 1904 to 1908. A comparison of the original records of this field work for well No. 1 with well No. 16 of the Fresno District shows a generally lower elevation of the ground water in recent years. The results are shown in Fig. 2.

Twenty-one wells were observed at the Kearney Vineyard by the College of Agriculture, University of California, during 1914, 1915 and 1916, and for 1920, 1921 and 1922. The average diversions and the rainfall in the earlier years were slightly larger than in the latter three years. The average depth to ground water on October 1 was 5.8 feet for the first three years and 8.0 feet for the latter years.

The city of Fresno is excluded from the Fresno Irrigation District although some canals cross the city. The Fresno City Water Corporation secures its water supply by pumping from wells within the city, the present draft being about 20,000 acre-feet per year. The ground water is now lower than formerly, as discussed later in detail.

In some parts of the district where the lands had gone back to pasturage, due to the rise of the ground water, plantings are being made. The general impression gained from field observation is that the new plantings are encroaching on the area formerly water logged and alkaline rather than the reverse. This also indicates that ground water conditions in such areas are improving.

It is not possible to specify any single item as the cause of the general ground water changes that may be occurring. Among probable

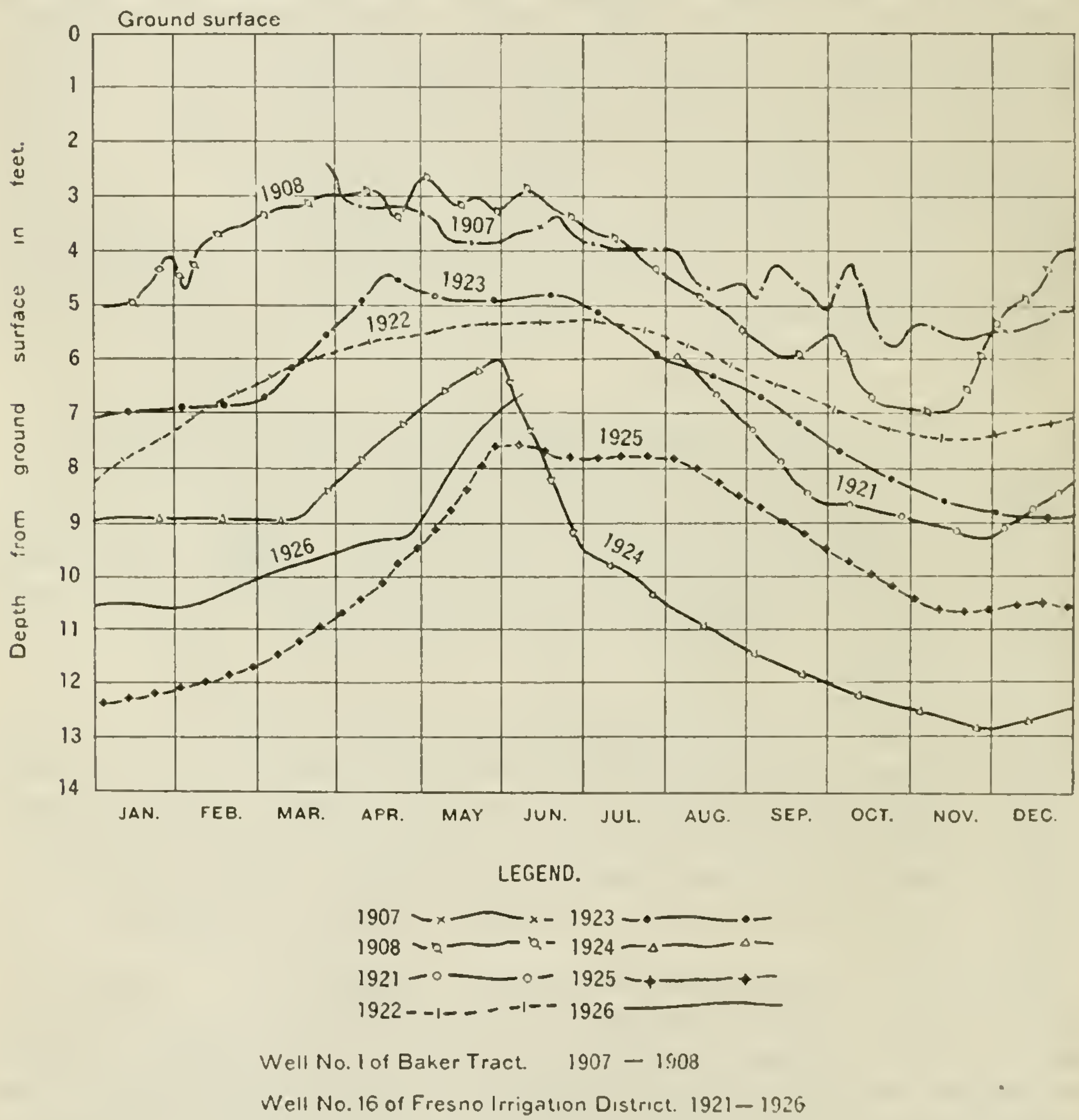


FIG. 2. Comparison of ground water levels 1907-1926 in Fresno Irrigation District.

causes would be more careful use of water on the land, a better maintained canal system, more regular delivery methods and the increase in pumping draft. While all of these factors may affect the result, the increased pumping draft is regarded as the most important single factor. While there may be some doubt regarding the relative effect of these different factors it is considered that the available data fully support the conclusion that ground water control has been established in this district. A recurrence of an injurious rise of the ground water is not to be expected.

GROUND WATER FLUCTUATIONS FROM DECEMBER 1 TO MARCH 1.

The ground water fluctuations from December 1 to March 1 for the entire area under the Fresno Canal are shown in the following table:

Season	*Average ground water fluctuation from December 1 to March 1 in feet + = rise; — = lowering.*	*Rainfall from December 1 to March 1 in inches*	*Diversion in acre-feet per acre of combined canal and pump service area*
1921–1922	+1.2	8.12	2.02
1922–1923	+ .2	4.04	1.93
1923–1924	— .6	1.09	2.12
1924–1925	+ .4	3.99	.96
1925–1926	+.01	3.26	2.4

Canal diversions during the winter months are usually small. In 1924–25 about 35,000 acre-feet were diverted by the Fresno Canal in these months; in the other years shown in the table the diversions were less than 10,000 acre-feet. The mean precipitation at Fresno for these three months is 4.45 inches.

In Fig. 3, the ground water fluctuations during these winter months have been plotted against the rainfall for the same months for the seasons covered by the records. The results are shown for the Fresno and Gould Canal areas as a whole and also for selected smaller areas under the Fresno Canal. In general a consistent relationship is shown. The preceding table shows that the ground water fluctuations during the winter are not directly related to the amount of diversion during the preceding summer.

For all lands under the Fresno Canal the results for the different years fall quite consistently on a straight line relationship. The results for 1924–25 are probably affected by the larger canal diversions during that winter. For the area under the Gould Canal, the ground water records do not include the seasons prior to 1923. A consistent relationship is indicated by the records of the three seasons shown on Fig. 3.

For the entire areas under the Fresno and the Gould canals, an average rise of 0.3 and 0.1 feet, respectively, is indicated by Fig. 3 in winters of normal precipitation. In such years the additions to the ground water from the run-off of adjacent areas and winter canal diversions appear to exceed slightly the pumping during this period and such outward ground water movement into lower areas as may occur. In seasons of large precipitation some penetration of rainfall within the area to the ground water may occur although the amount of such penetration with present depths to ground water is probably small.

For the smaller areas under the Fresno Canal differences in the winter fluctuations are shown in Fig. 3. The Dry Creek Canal serves lands west of Fresno in the lower portion of the district. The Fancher Creek Canal serves lands south of Fresno. Both areas are distant from any large stream channels having continuous flow. The elements of supply appear to exceed the elements of use for the Dry Creek Canal area and a small rise in winters of normal rainfall is indicated. For the Fancher Creek Canal, the elements of supply are sufficiently large to result in a rise in all winters except those of very small rainfall.

The Herndon Canal serves lands along the San Joaquin River in the western part of the district. The ground water slopes away from this

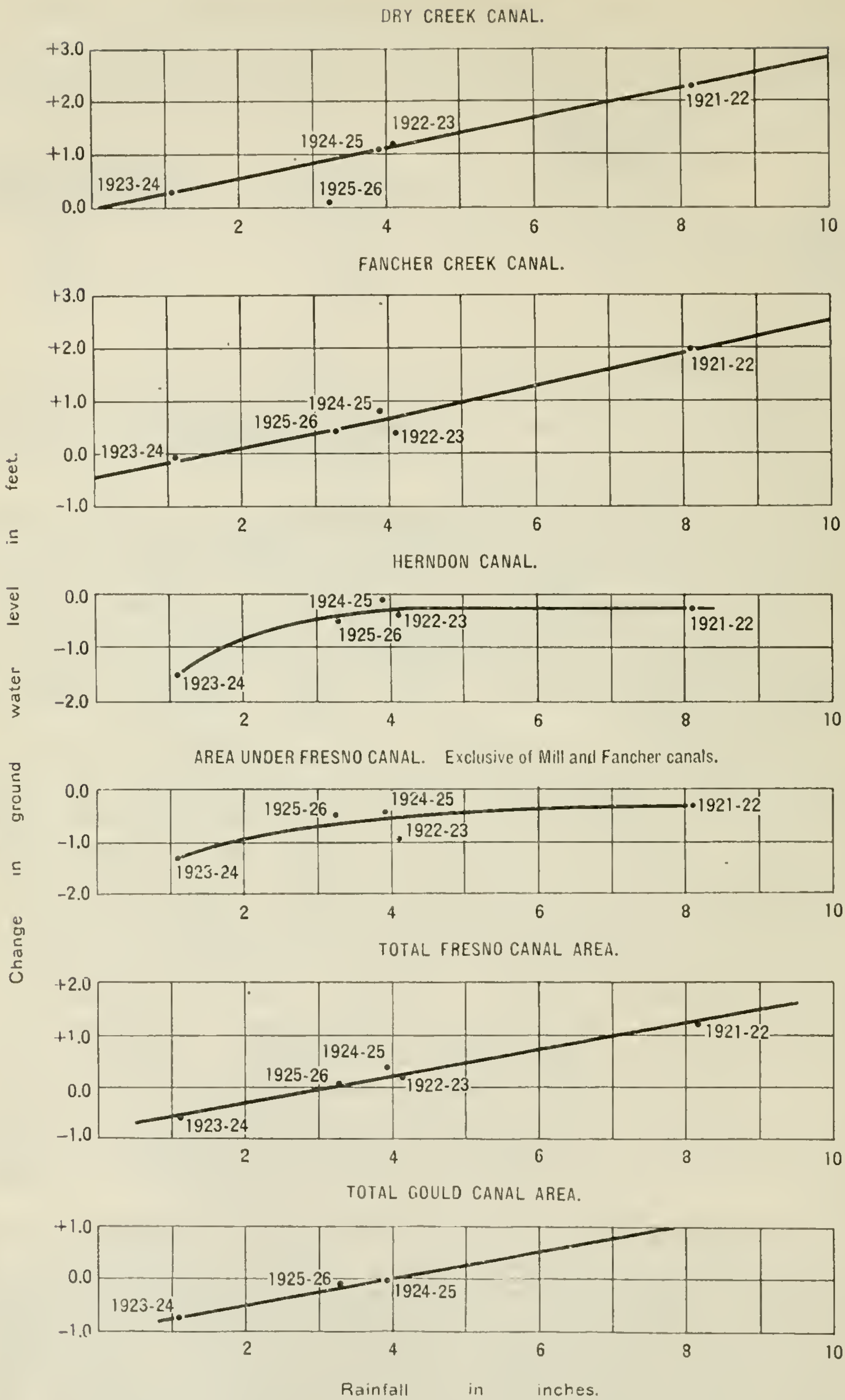


FIG. 3. Relation of change in level of ground water during December, January, and February, to rainfall during the same months, in Fresno Irrigation District.

area on all sides as shown by Map No. 1. The ground water lowers in all winters the outward movement even in years of large rainfall appears to exceed the elements of supply.

The area under the Fresno Canal exclusive of the Mill and Fancher Creek canals consists of an area in the southeastern part of the district below the area under the Gould Canal and adjacent to but above the Consolidated Irrigation District. The ground water has lowered in all winters covered by the records. Outward movement appears to exceed movement into the area from higher lands.

GROUND WATER FLUCTUATIONS MARCH 1 TO DECEMBER 1.

For the main canal delivery and crop growth season, the ground water fluctuations vary with the extent of the canal supply. The records of the Fresno District include the water delivered to main laterals and the area served, both by canals and by pumping under each lateral. The ground water fluctuations have been averaged for the same areas.

Water delivered into any area is used mainly to supply the moisture consumed by the crops and evaporation from the soil within the area. Some outward ground water movement may occur, also inflow from higher areas may be received. Any difference in the balance of items of supply and items of use will be reflected in the ground water fluctuations.

The areas reported as irrigated are the total areas of the farms receiving service; not all of the area of each farm may be actually cropped. However, the development in this district is relatively intensive and the proportion of unused land on the developed farms is relatively small. There are, however, farms on which no service is received, the lands being undeveloped. These lands are excluded from the crop area. Ground water fluctuations affect the gross area; crop use applies only to the area actually growing crops. If only a portion of any area was irrigated, the resulting ground water fluctuations from any rate of delivery per acre of crop would be changed. For the six canal areas for which comparisons are presented the areas are as follows:

	Area in Acres				
Canal	*Gross area*	*Area receiving canal service*	*Area receiving pump service*	*Undeveloped area*	*Per cent developed*
Herndon	55,944	41,839	5,713	8,392	85
Dry Creek	49,988	25,809	4,186	19,993	60
Mill Creek	110,403	71,009	10,638	28,756	74
Fancher Creek	50,120	37,036	8,794	4,290	85
Entire Fresno Canal	168,622	113,990	21,482	33,150	80
Gould Canal*	73,311	49,387	8,902	15,052	80

* Includes the Enterprise Canal.

The four years covered by the ground water records include 1924, in which the canal supply was only about one-half normal. The remaining three years varied somewhat in the amount of the diversion. Due to the early priority of the rights of this district the diversions vary less widely than the run-off of Kings River.

The ground water fluctuations and the average diversion per acre of cropped area are shown for the areas under the Fresno and the Gould canals in the following table. The fluctuations are for the

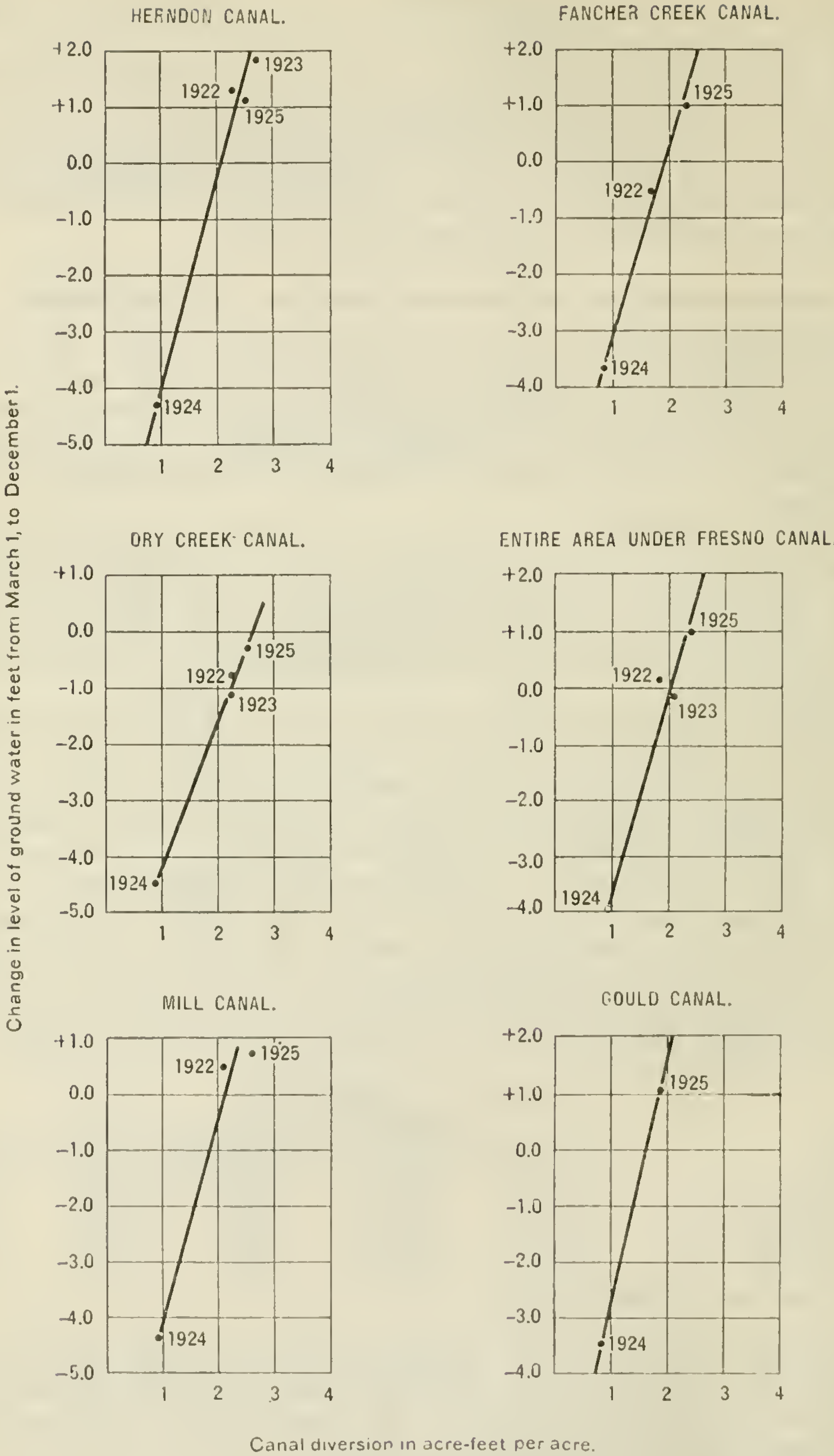


FIG. 4. Relation of volume of water diverted by canals to change in level of ground water in areas under canals in Fresno Irrigation District.

period March 1 to December 1 which includes nearly all of the canal diversions and the pumping for irrigation.

	Fresno Canal Area		Gould Canal Area	
Season	*Diversion in acre-feet per acre of total crop area*	*Average fluctuation of the ground water in feet*	*Diversion in acre-feet per acre of total crop area*	*Average fluctuation of the ground water in feet*
1922	1.93	+0.15	1.91	--
1923	2.12	—0.15	1.57	--
1924	.96	—3.95	.81	—3.5
1925	2.3	+1.0	1.9	+1.1
Total for four year period		—2.95		

The ground water lowering for this four-year period has been less than that in almost any other area in the southern San Joaquin Valley for the same period.

In Fig. 4 the fluctuations of the ground water from March 1 to December 1 are plotted against the delivery of water in terms of acre-feet per acre of the area of combined canal and pump service for six areas. Herndon and Dry Creek canals are part of the Mill Creek Canal; Mill Creek and Fancher canals comprise the larger part of the area under the Fresno Canal. The Gould Canal serves a separate area in the upper portion of the district. The ground water records under the Gould Canal cover only the last two years.

For all six areas a fair consistency is shown, the resulting fluctuation being proportional to the amount of water received per acre of total crop area. As all of the area of the Fresno District is above or distant from any large streams the ground water fluctuations during the summer months is dependent on the canal supply. This is also indicated by the fact that ground water prior to irrigation was at depths of 60 feet as compared to depths of less than 6 feet in much of the district in recent years.

A part of the canal service area has supplemental pump supplies available. The shortage in canal supply in 1924 of about one acre-foot per acre resulted in a lowering of the ground water of about 4 feet, the supplemental pumping draft on the ground water storage replacing a part of the deficiency in canal supply. In 1925 with a canal supply in excess of the average diversions of recent years, ground water storage resulted in refilling about one foot in depth of the 1924 depletion. The lower ground water in 1925 may have resulted in some reduction in loss of moisture by soil evaporation in areas formerly having ground water within 4 feet of the ground surface.

Fig. 4 also furnishes a basis for estimating the rate of delivery required to maintain the ground water in addition to supplying crop needs. To permanently maintain the ground water the average delivery should equal the water used both by crops and in any outward ground water movement. If this average delivery is maintained no progressive lowering or rise should occur although fluctuations would occur from year to year as the supply of each year was above or below that required to meet moisture consumption.

The supply required to meet moisture requirements without progressive ground water changes for the period March 1 to December 1 as indicated by the data at hand would be represented by the intersection of the lines shown in Fig. 4 with the coordinate of zero ground water fluctuation. The intersections vary for the different areas.

For the Herndon Canal area a delivery of about 2 acre-feet per acre of crop area appears to be required to support crop use and maintain the ground water. This area consists largely of trees and vines. The ground water slopes outward in three directions and some movement into other areas may occur. The similar figure for the Dry Creek Canal area would be 2.6 acre-feet per acre. This canal serves a larger area of forage crops; it also has had ground water within 6 feet of the surface in past years. Only 60 per cent of the gross area is now irrigated. As part of the indicated use may be ground water outflow a less rate of use per acre would be required to supply both crop use and outflow when a larger proportion of the area is irrigated. It is the only area shown on Fig. 4 in which lowering has occurred in each of the last four years. The wells observed under the Dry Creek Canal are located mainly in the upper portion of the area served and do not cover the western portion.

For the areas under the Mill Creek and Fancher canals Fig. 4 indicates a requirement of about 2 acre-feet per acre to supply crop use and maintain the ground water. A similar amount is indicated for the average of all of the area under the Fresno Canal.

For the Gould Canal a requirement of about 1.65 acre-feet is indicated by the two years' record available. This area is almost wholly in vines and trees. The ground water is all below the depth of influence of surface evaporation. Consumptive use would be expected to be a minimum in this area. The results do not leave any large amount of supply unaccounted for and outward movement appears small. The soils in this area are heavier and the movement of moisture slower.

The results for these different areas are consistent when local factors are considered. Apparently consumptive use as small as 1.65 acre-feet per acre can be realized for areas of trees and vines. For areas of largely trees and vines but subject to the larger use of other types of crop on some of the area, or where outward ground water movement occurs a use of 2 acre-feet per acre may be required. For areas of mixed crops including forage, with some high ground water a consumptive use in excess of 2 acre-feet per acre may be required.

Fig. A represents only the ground water fluctuations from March 1 to December 1. The supply delivered into each area should not only balance the ground water for this period but should also balance the average fluctuation for the winter period. If the ground water lowers one foot in the winter months, the supply during the remainder of the year should result in a rise of one foot if the balance for the full year is to be obtained. The combinations of ground water fluctuations for both the winter and summer periods indicate the following:

Canal area	*Winter fluctuation in normal years, feet*	*Estimated acre-feet per acre required to maintain ground water for entire year*
Herndon	—0.4	2.25
Dry Creek	+1.3	2.15
Mill Creek	+0.3	2.2
Fancher	+0.4	1.85
Whole Fresno	+0.3	2.0
Gould	+0.1	1.65*

* Based on 2 years record only.

For the whole year there is less difference between the different areas than for the period March 1 to December 1 only. The winter rise under the Dry Creek Canal reduces the delivery required during the remainder of the season. For the Herndon Canal the lowering of 0.4 feet in the three winter months would be at the rate of 1.6 feet per year. If this lowering is assumed to be due to outward ground water movement, a consumptive use of only 1.6 acre-feet per acre would be indicated by Fig. 4 for this area. As this area is largely in trees and vines this result is consistent with the results for the Gould Canal.

The estimated rates of consumptive use shown in the preceding table are based on the indications of the records of the last four years. During this period a material change has occurred in the extent of pumping and in the depth to ground water over much of the area of the Fresno Irrigation District. The conditions of use of moisture may not have become sufficiently stabilized under these changed conditions for the results based on the records for these years to represent the numerical values for consumptive use that may be found in coming years when conditions may have become less variable. The estimates shown are presented as an illustration of the method of analysis considered applicable in the study of ground water utilization and as an illustration of the apparent consistency of the results secured even in such years of varying conditions as those covered by the records in this area.

The consumptive use for any area represents the amount of water per acre of irrigated crops that needs to be brought into the area to supply the moisture actually consumed by such crops. The canal supply may be less than the consumptive use in some years provided excess supply is available in other years to equalize such deficiencies and that ground water storage may make the surplus supply of excess years available in years of deficient supply. Any shortage in the average supply below the amounts required for consumptive use will result in a reduced crop production. These requirements for consumptive use differ from those for ordinary diversion in which only the requirements of surface application are considered without recovery of losses to the ground water by pumping. In such supplies for surface application alone, the requirement is more usually expressed in terms of the maximum diversion in any year. Some shortages in such maximum requirements can occur in occasional years without serious injury. Any shortage in the average supply for the requirements for consumptive use will result in crop injury or in gradual lowering of the ground water if ground water storage is drawn upon to replace such shortages.

Drainage Factor.

The amount of water made available by a lowering of the ground water depends on the proportion of the soil volume that is filled with water which is yielded by such lowering. This proportion may be termed the drainage factor. It is less than the total pore space of the soil material as the entire water contained will not be secured by a ground water lowering. The lowering of the ground water that

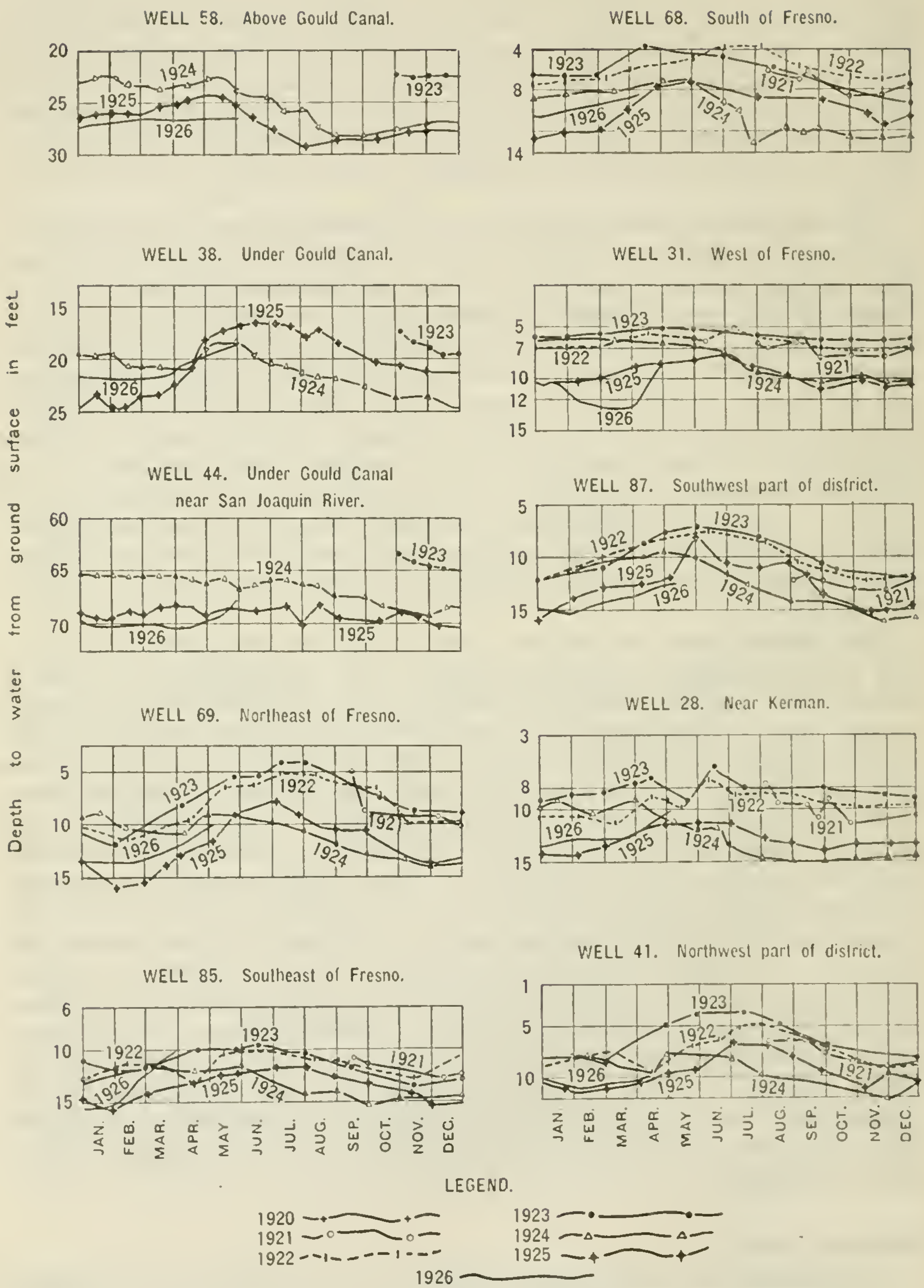


FIG. 5. Hydrographs of typical wells in Fresno Irrigation District.

resulted from the shortage in canal supply furnished a basis for estimating the drainage factor for this area. Such estimate is based on the assumption that the deficiency in canal supply in 1924 was replaced by the water represented by the ground water lowering. This assumption gives values of the drainage factor larger than the actual value as some shortage in the moisture secured by the crops occurred in 1924.

For the two-year period covering 1922 and 1923 the ground water in the area under the Fresno Canal remained at the same average elevation. In 1924 the ground water lowered an average of 3.95 feet. The canal diversions in 1922 and 1923 averaged 274,000 acre-feet. In 1924 only 130,000 acre-feet were secured. For the gross area under the Fresno Canal of 168,600 acre-feet, if the difference in canal supply of 144,000 acre-feet is considered to be replaced by the drainage of 666,000 acre-feet of soil volume, a drainage factor of 22 per cent is indicated. A similar comparison for 1924 and 1925 gave the same value for the drainage factor. Under the Gould Canal the records for 1924 and 1925 gave an indicated value of 20 per cent for the drainage factor.

These indicated values of the drainage factor are relatively large. They exceed the probable actual values as some shortage in crop use of moisture occurred in 1924. However the materials in this area are relatively open as indicated by the usually large discharges with small drawdown that are secured from wells. The indicated value for the area under the Gould Canal is larger relatively than that for the Fresno Canal, as the materials under the Gould Canal are of less open character.

Hydrographs of Typical Wells.

Hydrographs of typical wells are shown in Fig. 5. Well 58 is just above the Gould Canal. Lowering occurs during the summer months with a rise in the winter. Well 38 is about 2 miles southwest of Clovis in the irrigated area; it rises during the irrigation season and lowers in the winter. Over one-half the lowering in 1924 was recovered in 1925. Well 44 is near the San Joaquin River north of Fresno in an area of limited local irrigation. Less fluctuations with the canal delivery occurs.

Well 69 is just outside of Fresno. Direct response to canal flow is shown. Well 85 is about 4 miles southeast of Fresno. It has recovered the lowering in 1924. Well 68 is 5 miles south of Fresno and is typical of the fluctuations in this area of relatively high ground water. Well 31 is 7 miles west of Fresno. Only a small response to canal use is shown.

Well 87 is in the southwest part of the district, 3 miles southeast of Kerman. Well 28 is 2 miles north of Kerman and, like Well 31 to the east, shows less wide fluctuations during the year. Well 41 is in the northwest corner of the district. Irrigation has increased in this area in recent years and the ground water rose from 1921 to 1923; some lowering occurred in 1924.

Ground Water in the City of Fresno.

The Fresno City Water Corporation, which supplies Fresno, secures its water supply by pumping within the city from thirty pumping plants. These wells are located over the area served. Records of the draft and the fluctuations of these wells have been made available by the water company. Observations of the wells were begun in 1923. Several industries have their own wells. However the draft of the water company represents probably 80 to 90 per cent of the total draft within the city.

The ground water within the city of Fresno rose from depths of about sixty feet prior to irrigation to within a few feet of the ground surface. Difficulty was formerly experienced in cellar and foundation work within the city. The ground water has lowered in recent years so that these difficulties do not now occur.

The principal data regarding the draft and fluctuations together with comparative data for areas outside the city are shown in the following table:

	Year 1923	*Year 1924*	*Year 1925*
Draft by Fresno City Water Corporation in acre-feet	19,650	21,900	21,800
Average change in feet in ground water elevation in wells within Fresno City, December 1 to December 1		—2.2	+0.9
Average change in feet in ground water elevation in wells southwest of Fresno under the Dry Creek Canal	+.1	—4.2	+ .8
Average change in feet in ground water elevation in wells northeast of Fresno under the Enterprise Canal	—	—4.3	+ .8
Total diversion by Fresno Irrigation District in acre-feet	404,000	187,000	455,000

The data in the above table indicates that the ground water within the city is affected by the supply on adjacent lands. With practically the same draft by the water company in 1924 and 1925, the ground water lowered in 1924 and rose in 1925. In 1925 the fluctuations of the ground water in the city were similar to those in adjacent irrigated areas. In 1924 less lowering occurred in the city than in the adjacent irrigated areas.

The Dry Creek Canal of the Fresno Irrigation District crosses the city of Fresno. Some of the wells of the Water Company are located near the canal. Their fluctuations are not materially different from the average for all wells. The three wells nearest the Dry Creek Canal lowered more during the two years from December 1, 1923, to December 1, 1925, than the average of all wells.

Some differences in fluctuation occur in different parts of the year between the wells inside the city and those outside, as shown by the following table:

	Average fluctuations in feet			
	Wells in irrigated area northeast of Fresno	*Wells in Fresno*	*Wells in irrigated area southwest of Fresno*	*Pumping by Fresno City Water Corp. in acre-feet*
Dec. 1, 1923, to Mar. 1, 1924	— .4	0	+ .3	2,920
Mar. 1, 1924, to Oct. 1, 1924	—3.2	—3.7	—4.0	16,650
Oct. 1, 1924, to Dec. 1, 1924	— .7	+1.5	— .5	2,330
Dec. 1, 1924, to Mar. 1, 1925	+ .1	+ .7	+1.1	2,470
Mar. 1, 1925, to Oct. 1, 1925	+1.4	— .6	+ .4	16,920
Oct. 1, 1925, to Dec. 1, 1925	— .7	+ .8	— .7	2,440

From October 1 to December 1 ground water in the Fresno Irrigation District lowers due to reduction in canal diversions. In the city of

Fresno the ground water rises, the rate of pumping within the city being less than the rate at which the lowering of the summer is replaced. In the main summer months under adequate canal supplies as in 1925, the ground water in the city lowered while that in the district rose. This difference did not occur in 1924 under the conditions of deficient canal supply. A general draining from the higher to the lower areas is shown for the winter months, wells southwest of the city rising more than those in the city or to the northeast.

The data in the preceding table includes the pumping draft for the different periods. If the fluctuations are assumed to affect an area of 6000 acres with a drainage factor of 22 per cent, the ground water supply received can be estimated by balancing the draft and the water represented by the fluctuations. For the two winter periods this gives an indicated ground water inflow of about 1000 acre-feet per month. For the periods March 1 to December 1 the indicated ground water inflow is at the rate of about 2000 acre-feet per month in 1924 and 2400 acre-feet per month in 1925. For the period December 1, 1923, to December 1, 1924, a draft of 21,900 acre-feet resulted in a lowering of 2.2 feet indicating a ground water inflow of about 19,000 acre-feet. For the period December 1, 1924, to December 1, 1925, a draft of 21,800 acre-feet resulted in a rise of 0.9 feet indicating a ground water inflow of about 23,000 acre-feet. These results indicate the present ground water and canal conditions will result in a movement into the area drawn upon by pumping for the city of Fresno of as much as 20,000 acre-feet per year.

The pumping within the city of Fresno has resulted in a cone of depression in the ground water. The slope of the ground water from the northeast has been steepened and that to the southwest flattened. The maximum lowering from the normal slope appears to have been about 14 feet at the end of 1924.

Not all of the draft within the city of Fresno is a draft on the ground water of the area as a whole, as the sewer discharge is delivered to an area southwest of the city and added to the ground water there. This is pumped and used by the Fresno District. The amount of the sewer discharge has been measured during 1926, by the city of Fresno. The draft by the Water Company and the discharge of the sewers are given by months in the following table:

	Draft by Fresno City Water Corporation, acre-feet	*Delivery to sewer farm, acre-feet*
January	870	830
February	800	930
March	1,630	1,040
April	1,610	1,040
May	2,760	1,200
June	3,330	1,035
July	3,520	1,075

The excess of the sewer farm discharge over the city draft in the winter months is due to the sewers acting also as storm drains.

The records available appear to indicate that with existing ground water and canal conditions a pumping draft of 20,000 acre-feet per year can be maintained by the wells of the Fresno City Water Corporation without material increase in the present cone of depression. This represents a draft of over three acre-feet per acre of the gross area over which the pumps are distributed, and is a much heavier rate of pumping draft than has been found to be supported elsewhere in the valley. It is considered that the conditions are particularly favorable in Fresno for such pumping. The drainage factor is large, indicating open material. Relatively large discharges are secured from relatively shallow wells without excessive drawdown also indicating free movement of ground water. Fresno is surrounded by irrigated areas receiving canal service and is crossed by canals supplying some direct seepage. None of the wells within the city are more than two miles from irrigated areas. These favorable conditions do not occur in some of the other areas having heavy pumping drafts and the results in Fresno are not considered to furnish a criterion by which the results to be expected in such other areas can be predicted.

GROUND WATER IN THE CONSOLIDATED IRRIGATION DISTRICT.

The same character of records are available and the same method of discussion has been followed for the Consolidated Irrigation District as for the Fresno Irrigation District. The Consolidated District receives water by diversion from Kings River through its own canals and also through the Lone Tree Canal from the Fresno District. The Consolidated District also delivers water to the Island No. 3 District. The canal supply considered in the following discussion is the net supply of the area within the district boundaries.

Ground water is readily obtained throughout the district in wells of shallow depth. As the canal supply is available mainly only during a short season, pumping both as the entire source of supply and to supplement canal service has been extensively used.

Of the gross area of 149,888 acres in this district, 81,500 acres are reported as receiving canal service and 44,000 acres as being supplied entirely by pumps. The season of delivery under the canals is usually short, the water right of this district supplying less water in late summer months than that of the Fresno district. In consequence, nearly all land receiving canal service secures supplemental supplies for pumping.

The upper end of the area served by the Consolidated District near Sanger is adjacent to the upper end of the Fresno District and Kings River. The district extends to the southwest, being bounded by Kings River along the east. As shown on Map No. 1 the ground water in the portion of the district adjacent to Kings River slopes toward the river, the remainder has a slope in a general southwesterly direction. The ground water fluctuations vary within the district due to these factors of location. They also vary, depending on the relative areas of canal and pump service. In the western portion of the district there is nearly as large an area supplied entirely by pumps as there is supplied by canals; in the remainder of the district there is over three times as large an area under canal service as served by pumps alone. Satisfactory supplies can be secured from relatively shallow wells in all parts of the district.

GROUND WATER FLUCTUATIONS DECEMBER 1 TO MARCH 1.

The ground water fluctuations for the entire district for each winter for which records are available are shown in the following table:

Season	*Diversion in acre-feet per acre of combined canal and pump service*	*Average ground water fluctuation from Dec. 1 to Mar. 1 of the following winter, in feet*	*Rainfall from Dec. 1 to Mar. 1, in inches*
1922	2.05	—0.1	4.04
1923	1.75	—0.6	1.09
1924	.20	—0.05	3.99
1925	1.64	—0.4	3.26

In order to indicate the effect of the general ground water conditions on the ground water fluctuations during the winter months, the area of the district was divided into four parts representing approximately equal areas extending across the district from the northeast toward the southwest. These areas do not represent lands served by separate canals, as the distribution system extends in general across their boundaries.

The ground water fluctuations from December 1 to March 1 for each of these four areas are shown in Fig. 6. The greater tendency toward lowering in the upper portion of the district and the gain even in years of below normal rainfall in the lower areas are shown by these results. The rainfall for these months at Fresno was used for these comparisons. The average rainfall is 4.45 inches. The amount of rainfall required to maintain the ground water during these months appears to be as follows:

Area	*Inches rainfall December 1 to March 1 required to maintain ground water*	*Fluctuations that would occur with normal rainfall. Feet*
1	6	—.3
2	7	—.4
3	4	0
4	2.5	+.4
Whole district	4.5	0

If no rainfall occurred, the ground water in areas 1 and 2 would apparently lower an average of about 1.25 feet during the winter months. The lowering under the same conditions in areas 3 and 4 would be about 0.5 foot. This lowering would be the result of draft and ground water movement. If the draft is assumed to be uniform in both areas a draining out from the upper area of about 0.35 foot depth of ground water during these three months would be indicated. This would be equivalent to a draining out of 1.4 feet depth of ground water per year or about one-third acre-foot of water per acre. The difference in the fluctuations in these areas indicates that some outward movement of ground water occurs from the higher to the lower areas.

GROUND WATER FLUCTUATIONS MARCH 1 TO DECEMBER 1.

The average ground water fluctuations for the entire area of the Consolidated District together with the diversions are shown in the following table for the years covered by the available record. The ground water fluctuations are those from March 1 to December 1. The canal delivery is also received during this period:

Season	Diversion in acre-feet per acre of total crop area	Average fluctuation of the ground water in feet
1922	2.05	+0.45
1923	1.75	—0.15
1924	0.20	—3.15
1925	1.64	+0.55
Total for four-year period		—2.30

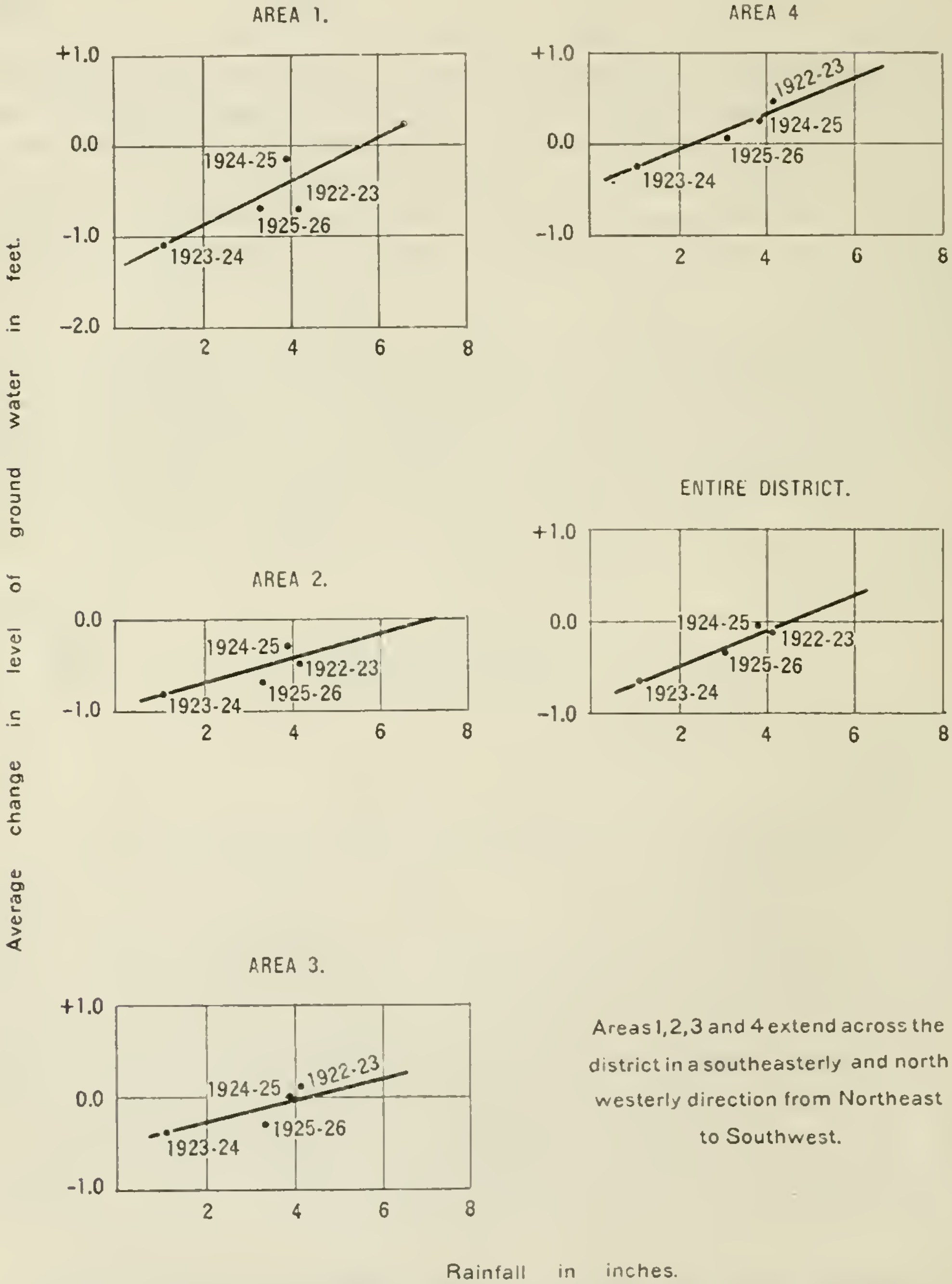


FIG. 6. Relation of change in level of ground water during December, January, and February, to the rainfall during the same months, in the Consolidated Irrigation District.

The available canal delivery records enable the ground water fluctuations and delivery of water to be compared for three areas in the district. One area consists of lands in the upper portion of the district, one of a larger area in the southeastern part of the district extending along Kings River and the third is the western half of the district.

The ground water fluctuations from March 1 to December 1 are plotted against the delivery of water per acre of total crop served by both canals and pumps in Fig. 7 for each of the four years covered by the records. These comparisons are made on a similar basis to those previously discussed for certain areas in the Fresno District.

In general a fair consistency is shown between the quantity of water delivered per acre of crop and the resulting ground water fluctuations.

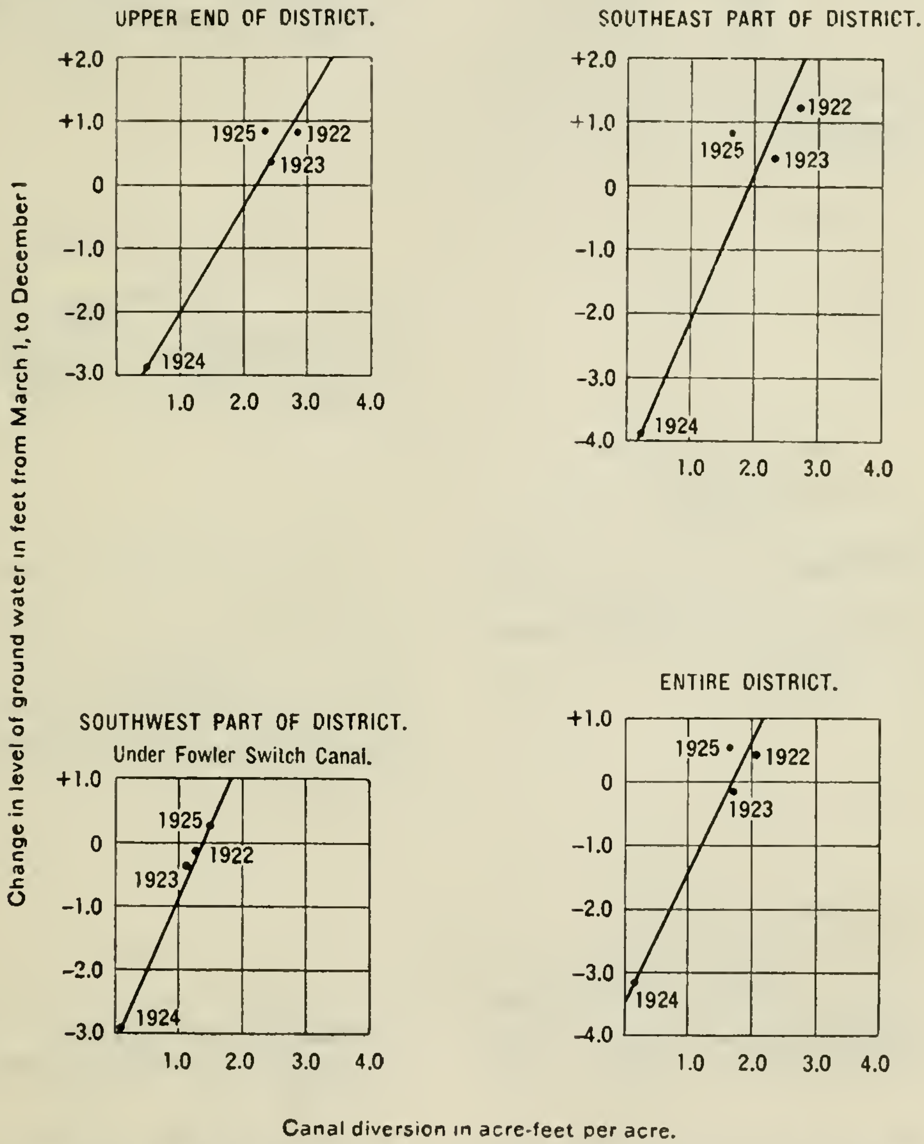


FIG. 7. Relation of volume of water diverted by canals to change in level of ground water, in areas under canals, in Consolidated Irrigation District.

The results for 1925 are less consistent with those for 1922 and 1923. In 1925 the general ground water was lower and losses by outward movement and from low areas usually wet were reduced.

For the upper area, in order to maintain the ground water, a delivery of about 2.25 acre-feet per acre appears to be required. For the area along the river with higher ground water as in 1922 and 1923, a requirement of slightly over 2 acre-feet per acre is indicated; for the conditions in 1925 less than 2 acre-feet appears to be needed. For

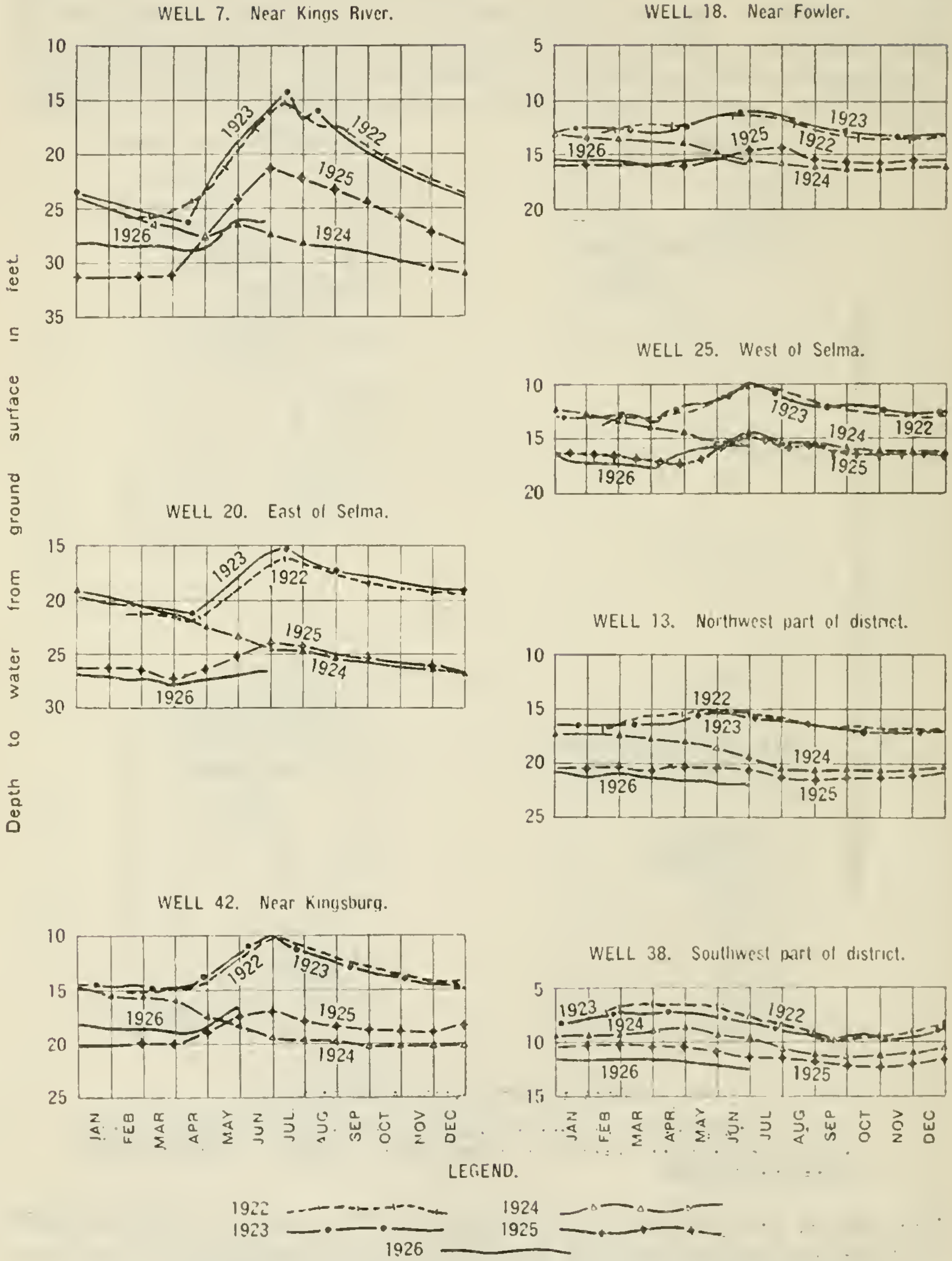


FIG. 8. Hydrographs of typical wells in Consolidated Irrigation District.

average conditions liable to occur in the future 2 acre-feet would appear probable. For the western part of the district a delivery into the area of 1.4 acre-feet per acre would appear to be sufficient to maintain the ground water.

These indications vary rather widely. The variations are relatively consistent, however, when the local conditions are considered. Outward movement would be expected to occur from the two upper areas which would increase the delivery required to maintain the ground water. Such movement into the lower area apparently occurs. For the whole district the average requirement for delivery into the district appears to be about 1.75 acre-feet per acre of area irrigated. The difference in the indicated requirement for the upper and lower area would correspond to a ground water movement into the lower and western area of about 0.35 acre-foot per acre which is in agreement with the indicated movement based on the fluctuations during the winter months.

The variations in evaporation from moist areas and reduction in outward movement due to the lowering of the ground water during the period covered by the ground water records prevent the making of an estimate of the drainage factor on the basis used in the Fresno Irrigation District. The probable drainage factor for the Consolidated District area would be expected to be as large as that for the Fresno District, as the soil materials are fully as coarse in texture.

If a value of the drainage factor of 20 per cent is assumed, for 1922 the total canal supply received in the Consolidated District minus the water represented by the rise of the ground water would be about 245,000 acre-feet Similarly for 1925 the total canal supply received in the district minus the water represented by the ground water rise would be about 190,000 acre-feet. If the same area of crop consumed the same amount of actual moisture in these two years, the indicated difference in outward movement of ground water and loss of moisture by evaporation from ponds and moist areas would be 55,000 acre feet. This would represent a reduction in ground water losses due to the lowering of the ground water between 1922 and 1925. Additional periods of record should be secured before dependence should be placed in the amount of this indicated difference. These results however are sufficient to indicate that a smaller canal supply will meet the crop requirements and maintain the ground water under the ground water conditions obtaining in 1925 than would be required under the conditions of 1922.

Hydrographs of Typical Wells.

Hydrographs of typical wells are shown in Fig 8. Well 7 is near Kings River south of Sanger; a rapid rise during the period of canal delivery and a similarly rapid lowering beginning in August is shown. Part of the lowering in 1924 was recovered in 1925. Well 20 is 4 miles east of Selma and about the same distance from Kings River. Little recovery in 1925 is shown. Well 42 is near Kingsburg and Kings River; some recovery in 1925 occurred.

Well 18 near Fowler shows little effect of canal service and a small lowering in 1924. Well 25, 2 miles west of Selma, shows the effect of use in the canals with a lowering in 1924 that was not recovered in 1925. Well 13 in the northwest corner of the district shows little monthly fluctuation and little lowering occurred except in 1924. Well 38 in the southwest part of the district shows the effect of the pumping in that area. Lowering has occurred in each year since 1923.

GROUND WATER IN LAGUNA IRRIGATION DISTRICT.

The pumping plants in the Laguna Irrigation District were canvassed by the district during the winter of 1924-25. A total of 108 plants were reported, of which nearly one-half had been installed in 1924. Open bottom, well point and perforated wells are used, about two-thirds of the plants being well points with from one to three wells per plant. All wells reported are relatively shallow, many not exceeding 50 feet in depth. No deep or artesian wells are reported and the conditions for obtaining such wells are not known. Judged by conditions to the west in the Riverdale District and the results with wells near Conejo to the east, wells of good yield, 600 to 800 feet deep, should be obtainable in the Laguna District.

The depth to water in 1924 varied from 6 to 15 feet; the conditions in 1924 resulted in a lower ground water than normal. Drawdown when operating averaged about 20 feet. The average discharge is about 0.8 second-feet. The plants installed at the time of this canvass had sufficient capacity to irrigate about 30 per cent of the area in the district. A material increase in the number of plants has occurred since 1924.

Ground water records were begun in this area in August, 1925. The records now available are not sufficient to permit a detail analysis of the ground water supply to be made. Available data support the conclusion that relatively inexpensive plants can be installed in this district, which can be expected to give discharges of about one second-foot with relatively small lifts. Under existing conditions of canal supply which result in a short season of delivery, such pumping plants should assist in controlling the ground water so that it does not rise to such heights as to become injurious as well as to supply supplemental irrigation.

GROUND WATER IN RIVERDALE IRRIGATION DISTRICT.

The records available for the Riverdale Irrigation District consist of a single series of measurements in 1921 and in 1924, and continuous readings begun in 1925. A comparison of 17 wells observed both in 1921 and in 1924 shows an average lowering of 6 feet.

In 1921 thirty-three wells were reported. In 1924 three times this number were in use. A large part of the increase occurred in 1924. The shallow wells are either of open bottom, well point or perforated type. The average depth to water was 13 feet with an average drawdown of 21 feet. The average discharge was one second-foot. The depth of open bottom wells varied from 100 to 200 feet, being greater in the eastern part of the district. Well point wells varied from 40 to 150 feet in depth, those in the eastern part of the area are of less depth than those in the western part. The perforated wells are generally from 80 to 140 feet in depth.

In addition to the shallow wells, 7 deep or artesian wells were reported. These are from 800 to 1550 feet deep and have an average discharge of over 2 second-feet.

There were sufficient pumping plants in this district in 1924 to supply about 40 per cent of the area of the district. There has been a material increase in the use of ground water since 1924. The extent of development of shallow wells is sufficient to demonstrate the feasibility of securing ground water supplies from relatively inexpensive plants in practically any part of the district. The presence of deeper strata in the western portion of the district is also demonstrated. While no deeper wells were reported in the eastern portion of the district, it is probable that such wells could be secured in this area also. With less expensive shallow supplies available the desirability of attempting to secure deeper wells may be questionable.

The Riverdale District receives its main canal supply during a relatively short season. Use is heavy during such periods with a resulting rise of the ground water. Pumping from shallow wells is beneficial both from the usefulness of the water pumped and also because of the resulting lowering of the ground water and drainage.

GROUND WATER SUPPLIES IN KINGS RIVER AREAS NOT DIRECTLY SERVED BY CANALS.

There is an area of about 180,000 acres lying between the Fresno and Consolidated Irrigation districts and the areas irrigated by diversion from Murphy and Fresno sloughs that is not irrigated. In the past the ground water has been at or near the surface in much of this area. The ground water slopes from the Fresno and Consolidated districts into this area. Surface overflow or ground water movement has resulted in the rise of the ground water to within a few feet of the ground surface. Much of the land is now alkaline. Definite information regarding its original condition is not available but much of it appears to have been of poor quality prior to irrigation.

This area has been regarded as a source of ground water supply and some development has been made by the James Irrigation District. All extensive developments planned in this area contemplate the conveyance of the water secured to other areas for use. There are some areas now securing water by pumping for use on the overlying land, but these are relatively small in extent and adjacent to the boundaries of the canal irrigated areas.

It has been generally assumed that where the ground water was within 6 to 8 feet of the surface loss from the ground water would occur due to capillary rise of moisture within the root zone of plants or by evaporation from the soil surface. Available information indicates that formerly much of this area had ground water within less than 6 feet of the surface and there are accounts of difficulties with miring teams and other incidents that indicate that water practically stood on the surface at times. Old roads were built on fills to avoid such difficulties.

Actual records of ground water in this area are not extensive. However no records indicate ground water in much of this area within 6

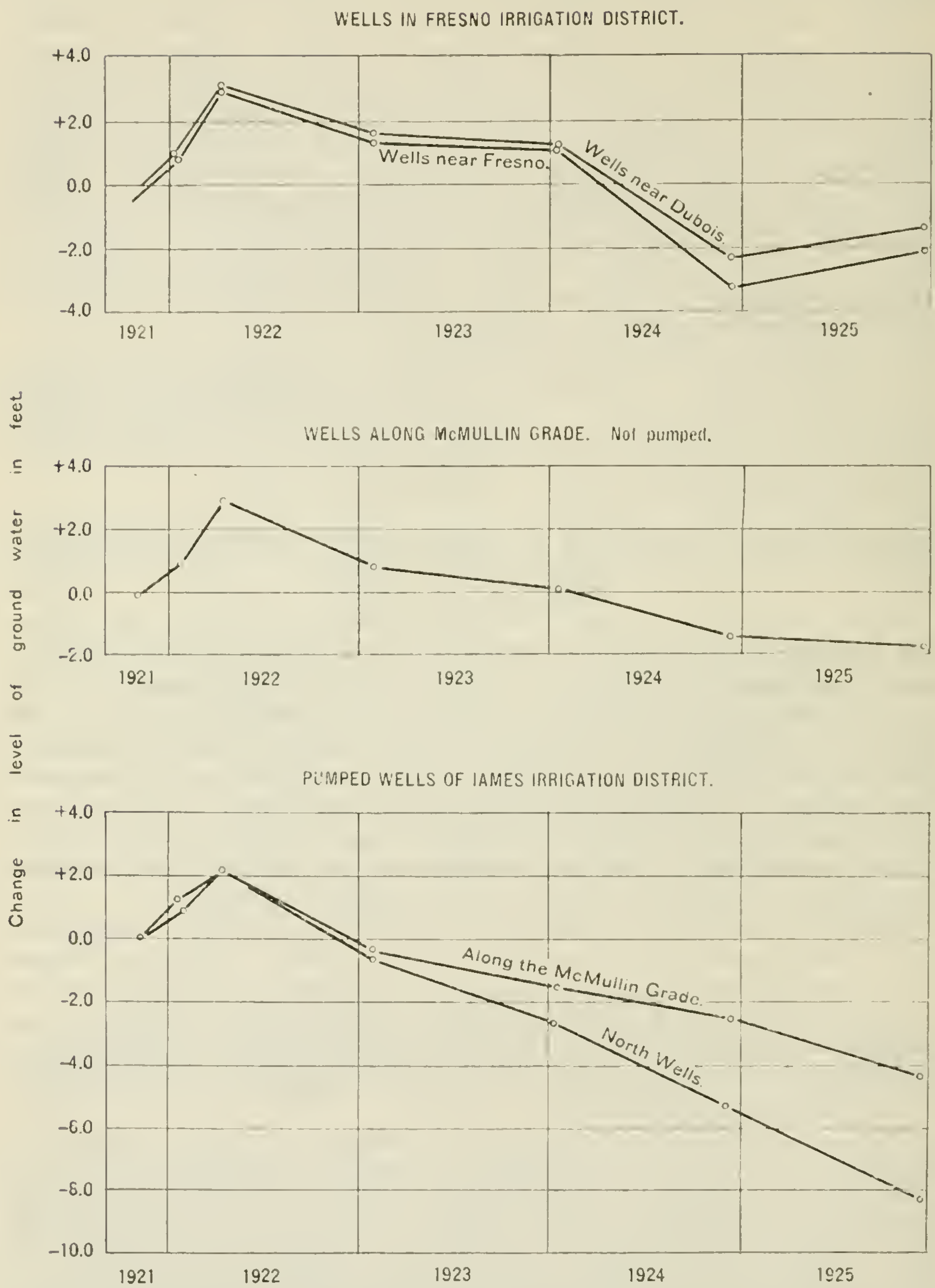


FIG. 9. Change in level of ground water, since November, 1921, in shallow wells of James Irrigation District and wells in adjacent areas in the Fresno Irrigation District.

feet of the surface in recent years. When the wells of the James District were drilled in the northern part of this area in 1920, the average depth of ground water in the wells was nine feet. This was prior to any draft in this area and following a period of average stream flow. This raises the question of what was the source of the water that formerly reached this area in sufficient quantity to cause water-logging and now has diminished so that lowering occurred without any local draft.

Irrigation in the Fresno area began about fifty years ago and increased gradually for many years. Available information indicates that some surface waste probably occurred in these earlier years although no records of its amounts are available. In more recent years the increase in the area irrigated and the closer management of the canals has resulted in the reduction and practical elimination of such waste.

Also in recent years pumping within the upper irrigation districts has increased rapidly. Such pumping would tend to intercept movement of ground water into this area. It is considered that the factors affecting the ground water prior to 1920 would be mainly the reduction in surface waste as pumping prior to that time was not as extensive as at present. If this conclusion is correct, ground water movement into this area was not sufficient by itself to maintain the ground water at or near the ground surface.

There is an additional area of similar general character in the southern part of this area between Kings River and Murphy Slough on the south and the Consolidated Irrigation District to the north in which some canal diversions occur. The direct diversions into this area make it difficult to segregate the effect of decreased diversions during recent years of below normal stream flow and any effects of changed ground water conditions to the northeast.

The James Irrigation District has two lines of wells operating in this area. One extends mainly in a north and south line into the area southwest of Kerman, the other extends along McMullin grade to Dubois. The wells vary from 150 to 300 feet in depth. The average discharge is about 2 second-feet per well. The total annual draft on these wells has varied from 6700 acre-feet in 1921 to 20,000 acre-feet in 1924.

No other adjacent wells were observed prior to 1925. The James District wells have been read when not operating during the winter season. Some lowering has resulted. There was an average lowering for the four years 1922 to 1925 of about 8 feet in the 17 wells extending to the north, of about 4.5 feet in the 14 wells along the McMullin Grade which were pumped and 1.5 feet for the 10 wells which were not pumped prior to 1926.

In Fig. 9 is shown a comparison of the fluctuations of these wells with wells in adjacent areas in the Fresno District, the dates used being those corresponding to the dates for which readings on the James wells are available. The group of Fresno District wells, near Dubois, represents the area nearest to the James wells, the other is in line with the ground water slope to the east and nearer Fresno. All wells rose during the winter of 1921-22. Over 8 inches of rain occurred in December, January and February of this season. The James wells lowered more during 1922 and 1923 than the wells in the Fresno District. In 1924 the wells in the Fresno District lowered more than those of the James District. In 1925 the wells of the Fresno District rose, those of the James District lowered.

Of the James District wells, those not used lowered less than those from which pumping occurred. The comparisons shown in Fig. 9 are considered to indicate that there is little direct response in the James wells to ground water fluctuations in the Fresno District. The James wells, near Dubois, being closer to the Fresno District and not pumped would be expected to reflect fluctuations in the Fresno District more definitely than the pumped wells of the James District. Except for 1922 which was effected by the heavy rainfall of the preceding winter, the unpumped James wells have lowered with little variation due to seasons or fluctuations in the Fresno District. The pumped wells have also lowered continuously at an increasing rate during the past three years. The increased rate of lowering is probably due to the increased pumping from these wells rather than any effect of conditions in distant areas.

Observations are not available on which to base an estimate of the area affected by the James wells. The wells are located so that they would be expected to intercept the ground water movement into an area of about 40,000 acres. The total draft for the four years, 1922 to 1925, has been 61,400 acre-feet, or at an average rate of about one and one-half acre-foot per acre, if the area affected is 40,000 acres. The total lowering at the wells has averaged about 5¼ feet for the same period. The average lowering over the whole area would be less than this amount. This draft is larger than would be made available from the lowering within this area and some ground water movement into the area is indicated.

There is no other extensive development in this area at present. Pumping is contemplated in the southern portion of the area near Murphy Slough. Test wells about 500 feet deep operated during part of 1926 showed discharges as large as 5 second-feet. It is planned to use the water so developed in an exchange of water between the Foothill Irrigation District and the Murphy Slough Association.

GROUND WATER IN FOOTHILL IRRIGATION DISTRICT.

About 20,000 acres of the 56,000 acres in this district are now supplied by local wells within the area. The discharge averages less than one-fourth second-foot per well and the water table has lowered materially in recent years. No systematic records of ground water fluctuations have been maintained, but both general observations and the opinions of land owners support the conclusion that the local sources of ground water supply are inadequate to support the existing draft.

The present planted area consists of about one-half vines and one-half trees, citrus representing nearly three-fourths of the latter plantings. The water requirements are less than for other types of crops.

The wells are generally from 75 to 200 feet in depth to the underlying rock. The lift has varied from about 12 to 14 feet before pumping to a present average of 80 to 90 feet.

The plotting of the depths to water reported in 1925 on the topographic maps of this area indicates that the present ground water is relatively flat having little slope either toward the hills or toward the Alta Canal on the west. The general ground water elevations appear to be about 25 feet lower than those to the west of, but adjacent to, the Alta Canal.

It is generally conceded that present development exceeds the ground water supply and that outside sources of supply must be obtained if the existing area is to be permanently maintained.

GROUND WATER IN THE ALTA IRRIGATION DISTRICT.

The Alta Irrigation District includes 129,300 acres of which 81,600 acres are reported as irrigated from the canals. While the larger part of the cropped area also secures supplemental water by pumping from wells, a relatively small area depends entirely on pumping. Some delivery of water from canals is also made to areas of pasturage in the southwestern part of the district.

The water rights of the Alta Irrigation District result in the district receiving its main water supply in the early summer months. No supply is usually received during August and September, a secondary supply is secured in October and November.

The main area of the Alta District is highly developed, principally in vines and trees. The southwestern portion of the district is used more largely for pasturage. Ground water supplies for pumping are available throughout the district at relatively shallow depths as shown on Map No. 2. Adequate yields are obtainable from shallow wells.

The ground water conditions in the different parts of the district vary. The ground water and canal delivery records have been separated for six different areas. The areas along Kings River represent the parts of the district within two to four miles of Kings River, whose ground water drains more directly toward Kings River, as shown on Map No. 1. The area north of Dinuba represents lands between the Kings River area and Smith Mountain. The central area consists of lands, mainly south of Dinuba, in the center of the district. The southeastern area consists of lands under several lateral canals lying east of Dinuba. The Button and Traver areas consist of the lands served by the district's canals of these names.

The same general method of ground water discussion has been followed as for the Fresno and Consolidated districts as the same character and extent of records are available. The year has been divided into the same two periods of a winter and a summer season.

GROUND WATER FLUCTUATIONS FROM DECEMBER 1 TO MARCH 1.

The ground water fluctuations during the winter months do not vary with the extent of the canal supply received during the preceding summer. Such fluctuations are, however, proportional in general to the amount of the rainfall during these months as shown in Fig. 10. As in the case of the Fresno and Consolidated districts, this variation of the ground water with the rainfall is not considered to represent direct penetration to the water table of the rainfall but to be due to the local run-off and pumping draft during these months which are themselves proportional to the rainfall. The rainfall plotted in Fig. 16 is that at Fresno for which the mean annual amount for these three winter months is 4.45 inches.

The available records of ground water fluctuation for the entire Alta District for the winter months are shown in the following table:

Season	*Diversion in acre-feet per acre of combined canal and pump service*	*Average ground water fluctuation from Dec. 1 to Mar. 1 of the following winter, in feet*	*Rainfall from Dec. 1 to Mar. 1, in inches*
1921	1.87	+0.45	8.12
1922	2.07	—0.30	4.04
1923	2.01	—1.30	1.09
1924	0.18	+0.15	3.99
1925	1.95	—0.30	3.26

The effect of drainage toward Kings River is noticeable for the Kings River area. The results for the years 1921–22 to 1923–24 are consistent. In 1924 the ground water lowered an average of 9 feet in this area, of which only 3 feet were recovered in 1925. Under the lower ground water of 1924–25 and 1925–26 a much smaller rainfall will apparently maintain the ground water in this area during these months than that needed for the conditions of the preceding years. The lower ground water elevation results in a smaller ground water slope toward Kings River with apparently a reduction in the rate of outward movement of ground water.

The area north of Dinuba shows similar characteristics to the Kings River area. The total ground water lowering in 1924 was about 15 feet, of which about 3 feet was recovered in 1925. The Central area gives results which are consistent for all years. The total lowering in 1924 was about 6 feet, of which about 1 foot was recovered in 1925. The change in ground water elevation does not appear to have changed the balance between inflow and outflow in this area. The southeast area shows a difference for the winter of 1924–25 with 1925–26 nearly similar to the results of the earlier years. Both the Button and Traver areas are ones in which only a small part of the area is irrigated. The lowering of 1924 does not appear to have made any material change in the winter fluctuation relationship.

With normal rainfall of 4.5 inches for these three months, a ground water lowering would occur in the areas along Kings River and north of Dinuba. A gain would occur in the Central, Button and Traver area. No change would be expected in the southeast area. For the entire district an average lowering of the ground water of about 0.2 foot would be expected.

GROUND WATER FLUCTUATIONS MARCH 1 TO DECEMBER 1.

The results for the entire area of the district are shown in the following table for the period March 1 to December 1:

Season	*Diversion in acre feet per acre of total crop area*	*Average fluctuation of the ground water in feet*
1922	2.07	—0.4
1923	2.01	+0.8
1924	.18	—8.65
1925	1.95	+1.5
Total for four year period		—6.75

The fluctuations of the ground water from March 1 to December 1 are compared with the delivery of water in acre-feet per acre for each of the four years covered by the records in Fig. 11. These, in general,

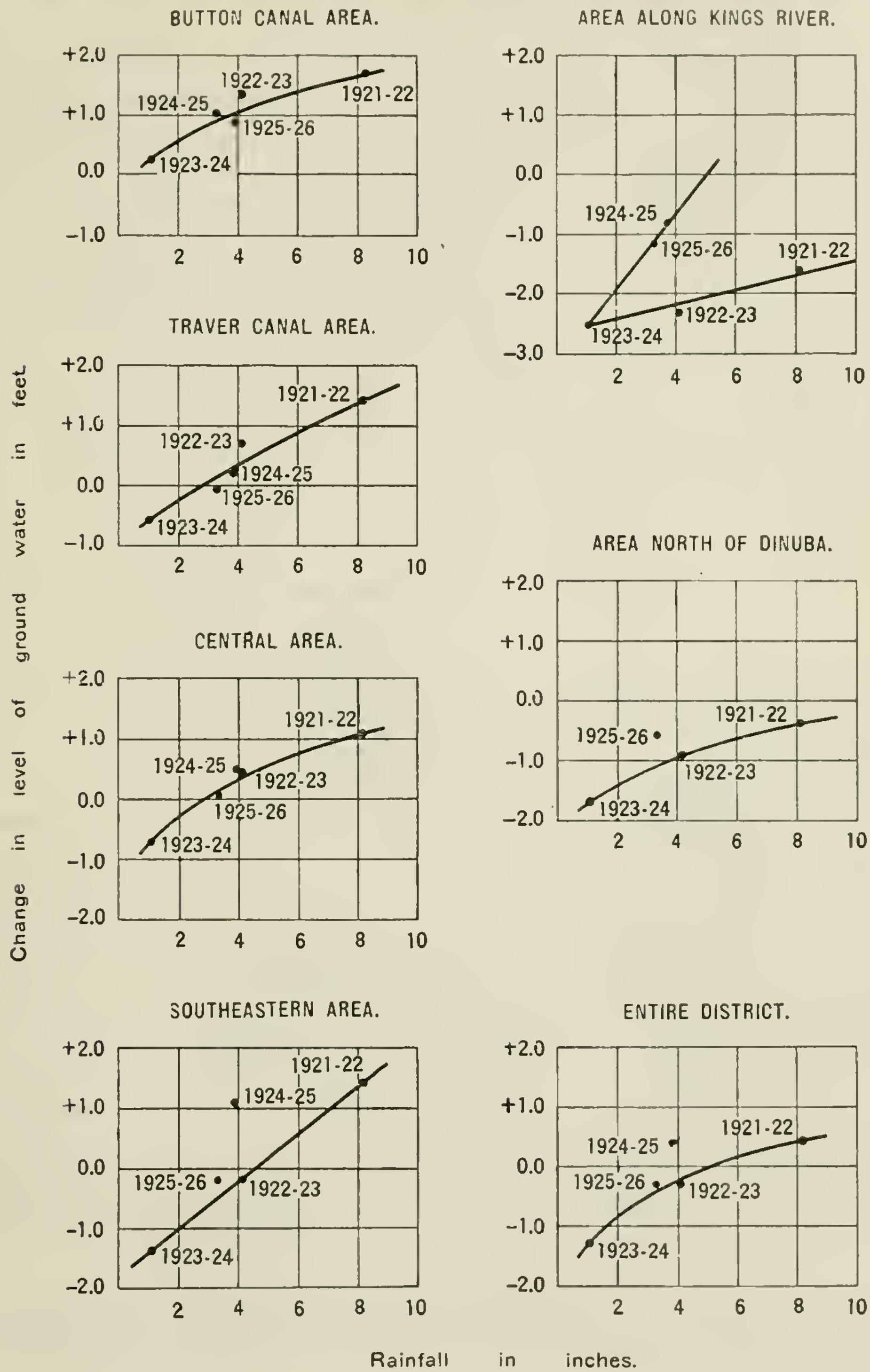


FIG. 10. Relation of change in level of ground water during December, January, and February, to the rainfall during the same months, in the Alta Irrigation District.

are fairly consistent. The same areas are used as for the winter fluctuations.

The ground water lowering in the entire Alta District in 1924 was larger than that in the Fresno or Consolidated districts. The average delivery per acre required to maintain the ground water is not materially different however. The following table gives the estimated supply required for each of these areas to meet crop needs and maintain the ground water under existing crop conditions. The results are based on the relationships shown in Fig. 11.

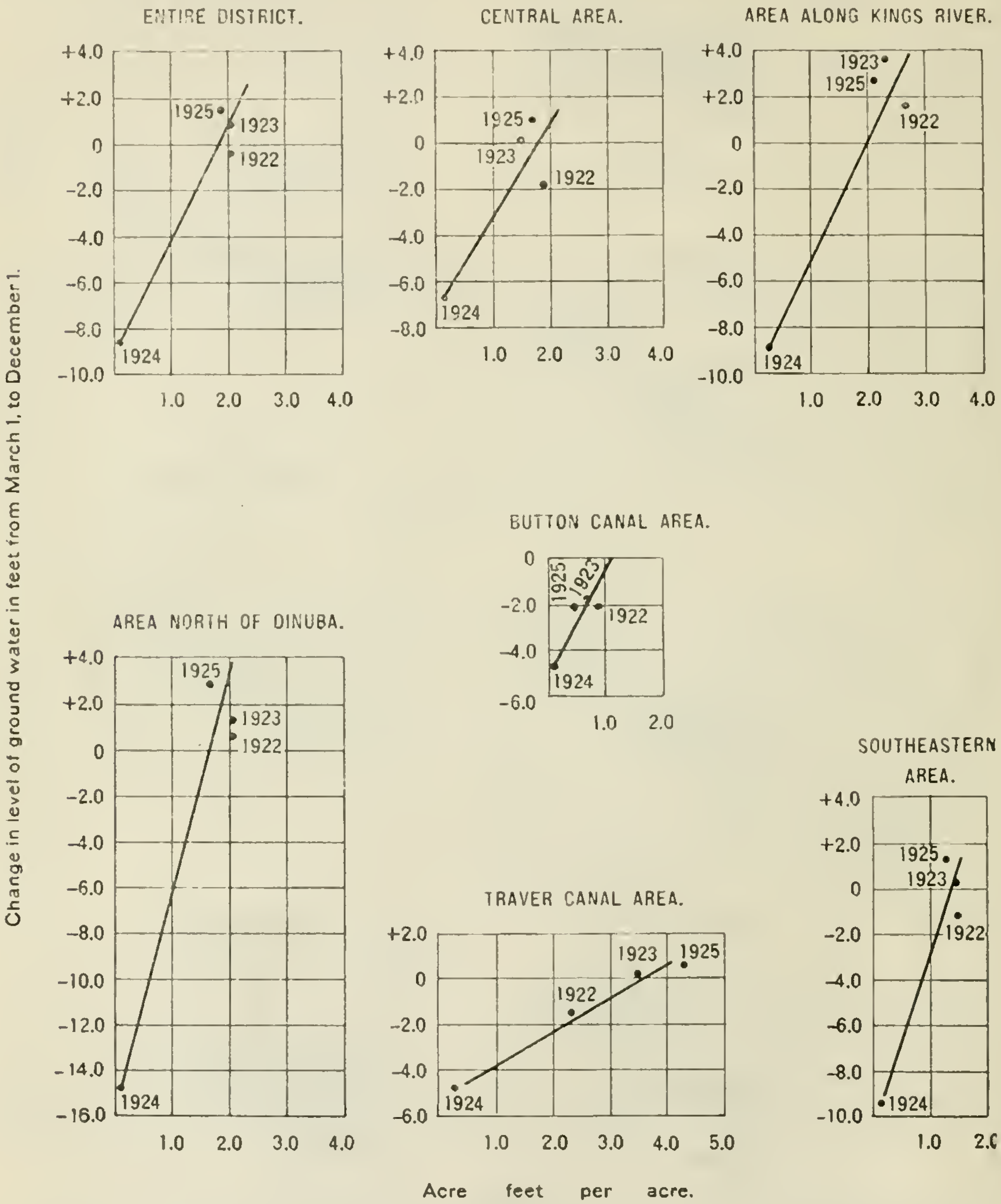


FIG. 11. Relation of volume of water applied in irrigation to change in level of ground water during the period March 1 to December 1, in areas in Alta Irrigation District.

Area	*Estimated supply required to maintain ground water March 1 to December 1, acre-feet per acre*	*Estimated supply required to maintain ground water for entire year, acre-feet per acre*
Along Kings River	1.9	2.25
North of Dinuba	1.8	1.9
Central	1.8	1.75
Southeastern	1.1	1.4
Button Canal	1.1	.9
Traver Canal	3.5	3.4
Entire district	1.9	1.95

As the crops in the Alta District are mainly trees and vines, the consumptive use of moisture would be expected to be similar to that found for areas of these crops in the Fresno District, except as the requirement of any area may be affected by ground water movement. The Central area is probably more nearly free from the influence of either ground water inflow or outflow than any other part of the Alta District, inflow apparently slightly exceeding outflow with a probable approximate balance. The larger requirement along Kings River is considered to be due to outward ground water drainage. While the sandier soils in this area result in larger applications of irrigation, such larger use would result in a rise of the water table were it not for such outward drainage. Some outward movement apparently occurs from the area north of Dinuba. Little supply is to be expected in this area from the run-off of the adjacent hill areas, as this is probably intercepted by pumping on higher lands in the Foothill District.

The indicated requirement for the southeastern area is less than would be expected. There is some uncertainty regarding the division of use under the East Branch Canal as between the areas north of Dinuba and this area that may effect this result. Less lowering occurred in the southeastern area in 1924 than north of Dinuba. Sand Creek passes through this area and some ground water supply from above may be received.

For both the Button and Traver canals the conditions are not similar to those for the other areas in that only about 20 per cent of the gross area is actually irrigated, although some water may be delivered to additional land for stock watering or occasional pasture irrigation. The figures given apply only to the present character and extent of use.

The Button Canal serves a long strip of land along the south boundary of the district north of Cottonwood Creek. About 5000 acres out of a gross area of 23,500 acres are classified as irrigated. A delivery of about one acre-foot per acre plus inflow of ground water appears sufficient to maintain the ground water under existing conditions. For the present area irrigated this would indicate a ground water inflow of only 3000 to 4000 acre-feet. For the irrigation of additional lands under this canal, a supply at a rate similar to that indicated for other areas would be expected.

For the Traver canal 5150 acres are reported irrigated in a gross area of 19,600 acres. The irrigated land is located mainly at the north end of the area. All water delivered has been assumed to be delivered to this irrigated area although some delivery for pasturage use is made to the remaining lands. In the past high ground water conditions in the lower part of this area have resulted in the loss of moisture by evaporation. The deductions for this area are only applicable under the existing conditions.

The amount of water represented by a fluctuation of ground water can be estimated from the available records. If the change in the ground water level in 1924 and 1925 is assumed to represent a volume of water equal to the difference in canal supply in these two years, a drainage factor of about 10 per cent is indicated for the upper hardpan lands and 20 per cent for the lower areas. As some shortage in use by the crops occurred in 1924, these indicated values probably exceed the actual drainage factor. The average drainage factor for the

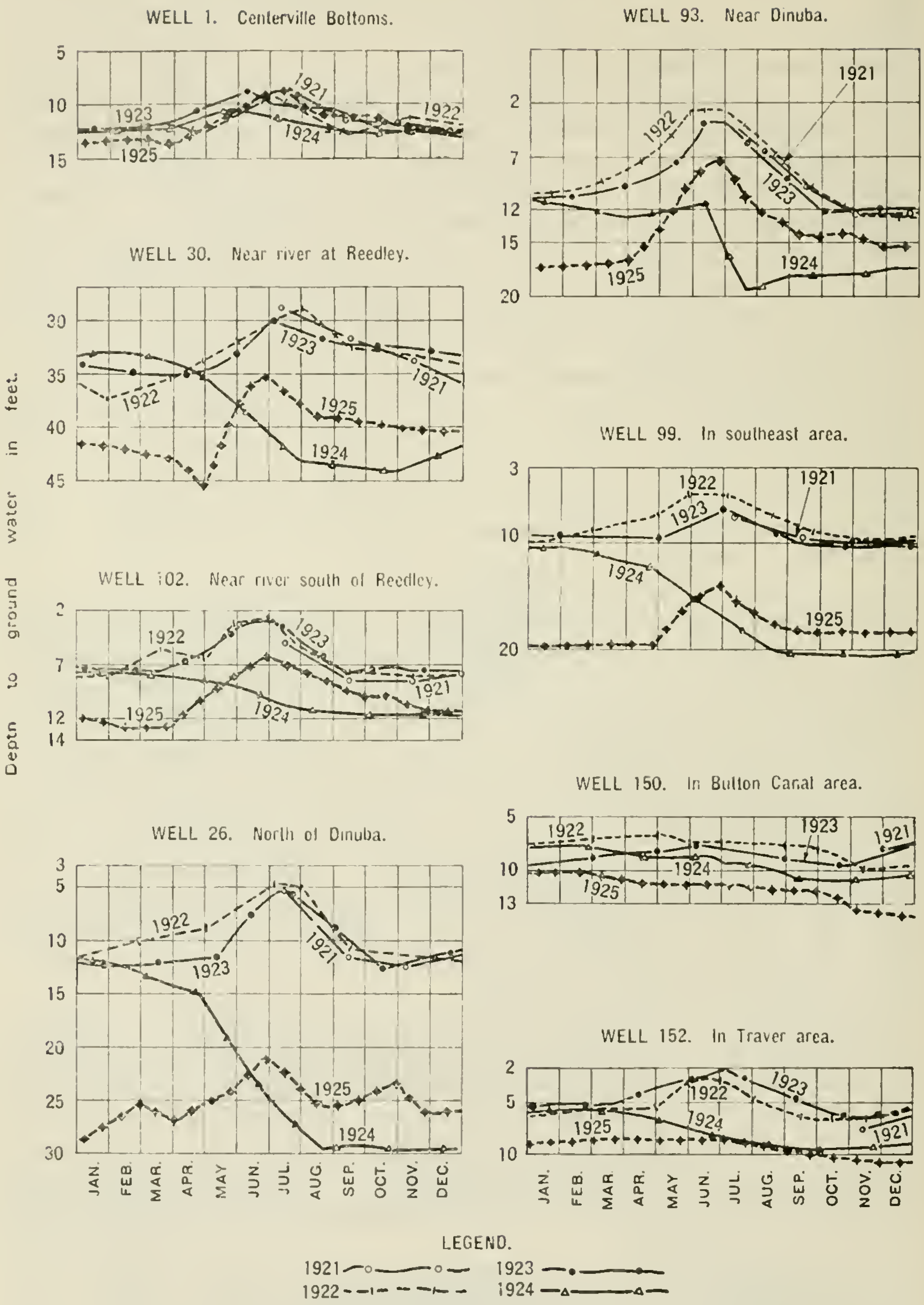


FIG. 12. Hydrographs of typical wells in Alta Irrigation District.

entire district is probably about 12.5 per cent. The ground water rose more in 1925 in proportion to the canal supply received than would have been expected from the records of the preceding years. The ground water in 1925 was an average of 9 feet lower than in 1922 for all of the Alta District. A canal supply of 165,000 acre-feet in 1922 resulted in maintaining the ground water without a rise or lowering. A canal supply of 156,000 acre-feet in 1925 resulted in an average rise of the ground water of 1.6 feet. For a drainage factor of 12.5 per cent this would represent 26,000 acre-feet of water placed in ground water storage and a remaining use of 130,000 acre-feet. Apparently the lower ground water in 1925 has resulted in a reduction of outward ground water movement and evaporation from areas of formerly high ground water of about 35,000 acre-feet so that a smaller canal supply will result in a rise of the ground water under the conditions of 1925 than was required in 1922. Additional periods of record should be secured before dependence is placed on the numerical amount of the indicated difference. These results, however, are sufficient to indicate that a smaller canal supply will maintain the ground water under the ground water conditions obtaining in 1925 than would be required under the conditions of 1922. The canal supply in 1925 less the indicated accumulation of ground water storage was at the rate of 1.6 acre-feet per acre of cropped area.

Hydrographs of Typical Wells.

Hydrographs of typical wells are shown in Fig. 12. Well 1 is in Centerville bottoms near the head of the Alta Canal. Very little lowering has occurred. Well 30 is near Kings River, just north of Reedley. Rapid lowering after the end of canal diversion is shown. Part of the lowering in 1924 was recovered in 1925. Well 102 is six miles south of Reedley and 2 miles from Kings River. Less wide fluctuations are shown than in well 30.

Well 26 is 5 miles northeast of Reedley and away from the river. A lowering of 18 feet occurred in 1924, of which only 4 feet was recovered in 1925. Well 93, 2 miles south of Dinuba, is in the Central area. The ground water prior to 1924 rose close to the ground surface. Well 99, in the southeast part of the district, shows less effect from canal delivery with about 10 feet lowering in 1924.

Well 150 is in the Button Canal area, near the eastern boundary of the district. There is little irrigation in this area and little monthly fluctuation is shown. Gradual lowering has continued during the period of record. Well 152 in the Traver area shows the effect of canal delivery in 1922 and 1923 and of its absence in 1924 and 1925. The ground water rose to within 3 feet of the ground surface in 1922 and 1923.

GROUND WATER IN AREA UNDER KINGS COUNTY CANALS.

The term Kings County Canals is generally used to describe the People's Last Chance and Lemoore canals, which serve adjacent areas on the south side of Kings River in Kings County. These canals serve an area having a relatively old irrigation development. The crops are diversified and include trees, vines, alfalfa, grain and pasture. Much of the area has had a relatively high water table and a larger portion of the land is used for pasturage on this account than in some of the other Kings River areas.

Ground water records are not as extensive under these canals as for the three upper districts. Some scattered records are available for earlier years. More extensive records were begun in the Lemoore area in 1924 and in the Last Chance and People's Canal areas in 1925.

The diversions by these canals are larger in proportion to the area irrigated than the practice on Kings River as a whole. Judged by the resulting ground water conditions, the diversions have exceeded the crop moisture requirements. This has resulted in a rise of the ground water to the extent necessary for excess soil evaporation to balance the surplus supply. Little outward movement of ground water appears to occur as the adjacent areas in the direction of the ground water slope as shown on Map No. 1 do not have available shallow ground water supplies. The depth of ground water and the closeness of the material also increase from the upper toward the lower portions of the area itself.

Lemoore Canal Area.

The Lemoore Canal serves the most westerly part of this area. Ground water slopes into the Lemoore area from the Last Chance area on the east. Some surface waste occurs at times into the channels of the South Fork of Kings River on the west, but there is little indication of ground water movement into such channels.

The ground water fluctuations reflect the variations in the canal supply as shown in Fig. 13. The ground water in the different parts of the area follows a similar variation; that in the southern part of the area averages about one foot lower than the ground water in the central and northern portions. In some areas the ground water rose to within 4 feet of the surface.

The diversions in 1925 were 95,060 acre-feet. For the gross area of 52,300 acres the diversion averaged 1.82 acre-feet per acre. This supply resulted in a net average rise of the ground water of 0.2 foot; apparently the diversions in 1925 were adequate to supply the crop needs and any losses by soil evaporation that may have occurred due to high ground water. While all of the gross area is classed as irrigated in the crop survey of this area, a considerable area of pasturage receives only partial service and the average use on the remaining area would be above the figure given. Based on the one year's records for 1925 a diversion into this area of 1.8 acre-feet per acre of gross area will apparently supply crop needs and maintain the ground water under existing conditions including the incomplete irrigation of present areas of pasture. A rate of diversion in excess of crop needs would be expected to result in a rise of the ground water until the excess soil moisture evaporation balanced the excess in supply.

Present pumping in this area is not as extensive as under many other Kings River canals. Twenty-three pumping plants were operated in 1925, having an average capacity of one second-foot. These wells are usually 40 to 100 feet deep. One well, 1517 feet deep, had a discharge of 3.2 second-feet.

Last Chance Area.

This area lies between the Lemoore and People's Canal area. The gross area is 33,180 acres, all of which is classified as more or less completely irrigated. The proportion of pasture is less than that in either of the adjacent canals.

Seventy-five pumping plants are reported as operated in 1925; the larger part of these were installed in 1924. The wells are relatively shallow, varying usually from 40 to 100 feet in depth. The average discharge is somewhat less than one second-foot.

The depths to ground water in this area increase from north to south. The fluctuations reflect the canal supply. Ground water slopes into the area from the People's Ditch area on the east and out from the area to the Lemoore area on the west. The ground water fluctuates with the

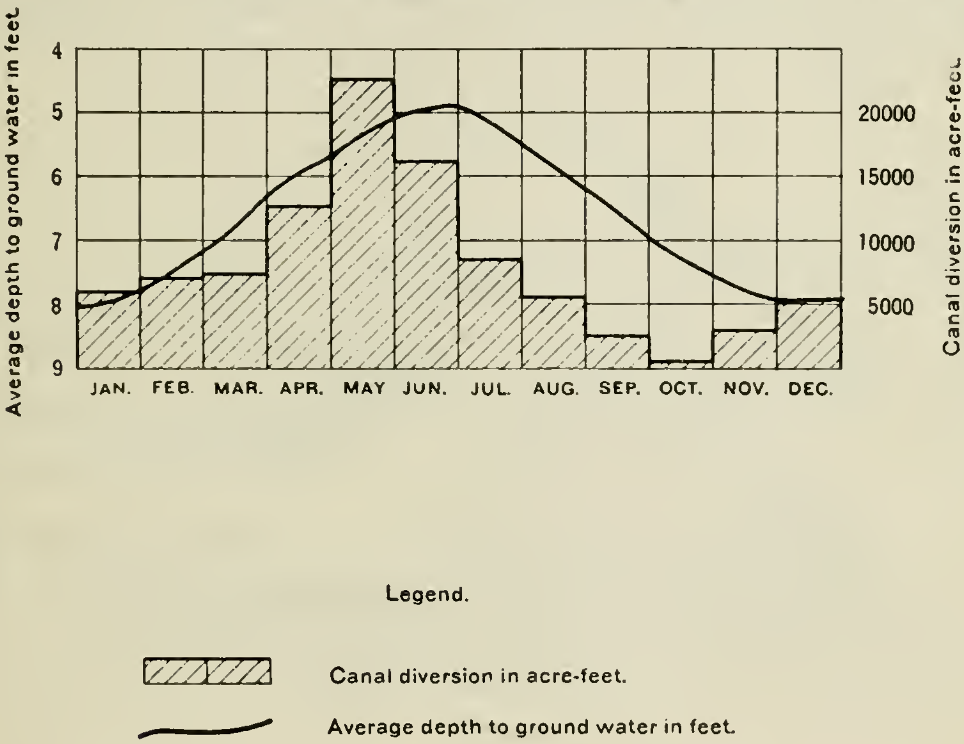


FIG. 13. Relation between canal diversions and change in level of ground water in Lemoore Irrigation District, in 1925.

canal delivery, as shown in Fig. 14. In 1925 the ground water rose within 4 feet of the surface in some wells.

For the whole area the ground water was 1.1 feet higher at the end of 1925 than at the beginning. The total diversion was 63,740 acre-feet, or 1.92 acre-feet per acre of gross area. Deducting the probable amount of water represented by the rise in the ground water, the one year's records for 1925 indicate a use of water by the crops of 1.65 acre-feet per acre of gross area. Rates of diversion in excess of crop use would be expected to result in a rise of the ground water until evaporation from the soil balanced the excess supply.

People's Ditch Area.

The gross area under this canal is 65,600 acres; about 40 per cent of this area is pasturage, the remainder being about equally divided between orchard and vines, alfalfa and grain.

Ground water records were not begun in this area until August, 1925. The depth to ground water for the remainder of 1925 varied from 9 to 11 feet. As these depths are greater than those for the same months in the adjacent Last Chance area, it is probable that the water in the People's Ditch area was also lower during the summer months than in the Last Chance area.

The number of existing pumping plants in this area is not known, although little development has taken place. General conditions are similar to those in the adjacent Last Chance area and shallow wells giving a discharge of about one second-foot should be obtained.

GROUND WATER IN VALLEY TROUGH AREAS ALONG NORTH SIDE CHANNELS OF KINGS RIVER.

This area includes the lands along Fresno Slough. It includes the Stinson, Crescent, James and Tranquillity irrigation districts and the

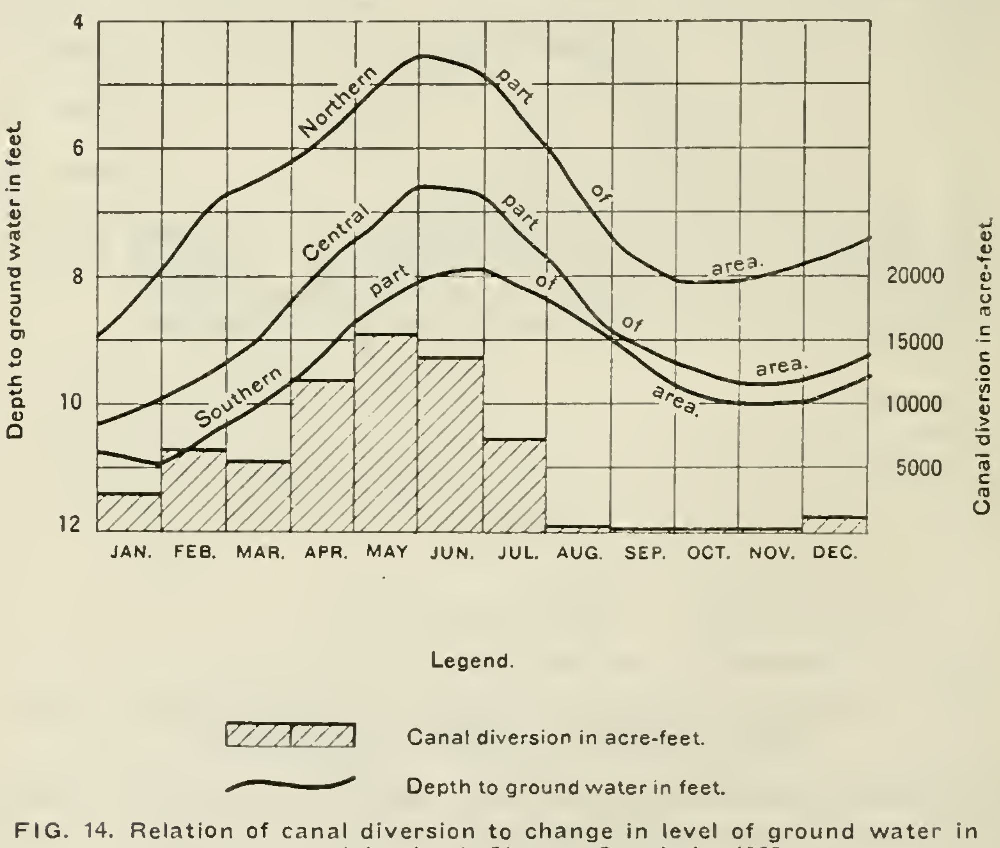


FIG. 14. Relation of canal diversion to change in level of ground water in area served by Last Chance Canal, in 1925.

Cuthbert-Burrell area. Pumping is practiced by both the Stinson and James districts as well as by individuals.

Cuthbert-Burrell Area.

For the Cuthbert-Burrell area, ground water records for about 30 wells are available since August, 1922.

The ground water contours shown on Map No. 1 indicate that ground water may move into this area from several sources. The direction of ground water slope from the western part of the Consolidated Irrigation District is toward this area. Water diverted by the Liberty and Big Mill Race canals might also reach the ground water in this area. General ground water in the Murphy Slough area including the Laguna and Riverdale Irrigation districts slopes partially toward this area.

In 1923 an average lowering of 0.6 foot occurred; in 1924 the lowering was 3.25 feet. In 1923 the flow of Kings River was about 80 per cent of normal; in 1924 about 25 per cent of normal. In 1925 with about 70 per cent of normal run-off an average lowering of 2.4 feet occurred. These amounts of lowering appear to be due to the deficiency in run-off of these seasons.

Stinson Irrigation District.

This district has 6 wells 800 to 1000 feet deep, which were formerly artesian, and 16 wells mainly 500 to 600 feet deep. These are used during the portions of the season when Kings River is not available. The district contains about 11,000 acres. The district was organized in 1921. The artesian wells were drilled prior to organization; the shallow wells have been installed by the district.

In 1925 the total pumping draft was 9924 acre-feet. The average discharge per well for both the deep and shallow wells was about 2 second-feet.

Sufficient records are not as yet available for these wells to enable an estimate to be made of the rate of draft which they can maintain without ground water depletion.

The quality of these waters has been previously discussed. It is desirable that other water should also be used on the same lands in order that harmful effects may be avoided.

Crescent Irrigation District.

This district has not installed pumping plants as a part of its water supply. There is only limited development by individuals in this area. One well 1130 feet deep furnishes a good yield. Ground water conditions appear to be generally similar to those in the Stinson District.

James Irrigation District.

This district operates wells 900 to 1200 feet deep located within the district as well as securing water from Kings River and from shallow wells to the east. The deep wells are perforated below the 700-foot level. One well, 1350 feet deep, encountered gas and salt in the lower portion in such quantities that 240 feet in the bottom of the well was plugged off. A second well, 4570 feet deep, has been abandoned because of the gas and brine produced.

Tests on a number of these wells were made in September, 1918. The pressure level was from 9 to 10 feet above the ground surface and sloped from the southeast toward the northwest, following the general direction of the local drainage. The rate of slope averaged 1½ feet per mile.

Thirty-four deep wells were operated by the James District in 1921. In other years the number has varied with the water supply secured from other sources and the crop needs. The average results for 1921 to 1924 are as follows:

Year	*Number of wells operated*	*Average discharge per well, second-feet*	*Mean operating lift, all wells, feet*	*Average operating lift for 4 wells operated each season*
1921	34	2.08	28.6	19.6
1922	11	2.08	25.0	23.6
1923	14	1.89	32.6	30.5
1924	24	1.54	39.3	37.8

Two results are shown for the average lift. One is the average of all wells observed in each season, the number of records being less than the number of plants operated, as the water stood below the pump bowls in some wells and could not be observed. The last column gives the average of four wells observed in each of the four years. The total draft in 1924 was 11,800 acre-feet. The four wells continuously read show a lowering of 18 feet in four years.

Summary.

Nearly all the ground water development in this area is from deep wells, shallow wells being used only in the Cuthbert-Burrell area. The term deep well is used for those wells penetrating strata of impervious material replenished from more distant sources, rather than from streams or irrigation adjacent to the well. Water in such deep wells is under pressure. Such wells in this area were artesian in the past and may flow at present in periods of small draft.

The relationship of shallow ground waters to local conditions of canal or stream supply is usually direct and positive, as indicated by the preceding discussions for other areas. The relationship of deep wells is indirect and more difficult to trace, particularly in quantitative terms. Ground water contours for deep wells indicate the direction of slope. However, fluctuations of deep wells reflect mainly changes in pressure head rather than depth of lowering of ground water and comparisons of draft and depletion can not be directly made.

Water from deep wells is obtainable generally on all of this area as well as along Kings River to the east. The depth generally increases toward the west. Wells within the Consolidated District penetrate heavy clays and enter water-bearing strata at 300 to 400 feet, which is under pressure and in some cases formerly flowed. Wells recently drilled west of the Consolidated District, near Cando, reached similar strata at depths of about 500 feet. Wells formerly artesian were secured in the Riverdale area at depths of from 800 to 1200 feet. The artesian wells in the James District are from 900 to 1200 feet in depth.

The details of the valley formation even to the depths penetrated by these wells are not known. There appears to be a sufficiently continuous impervious strata over much of this area to retain the pressure of the ground water in the underlying strata. This impervious strata may have been deposited when the valley was submerged and may conform to the topography of the valley at that time. This supposition might account for the less depth at which such impervious strata are penetrated nearer the eastern side of the valley.

No outcrops of the water-bearing strata from which such deep wells draw have been found or recognized. It is probable that they do outcrop under more recent alluvium near the eastern side of the valley, or that the upper edges of the impervious strata have been eroded exposing the underlying pervious strata to sources of absorption. The extent of such absorbing areas and the amounts absorbed are unknown. There is no information to indicate any source of absorption within the older formations of the upper stream courses and any water so absorbed must apparently be obtained below the points of measurements of the streams and so be accounted for in the records of visible water supply.

As previously discussed the available data do not indicate any material outward ground water movement from the area as a whole. If such deeper water-bearing strata have no outlet and are filled with water under pressure no movement of water through such strata would occur under natural conditions. For such conditions the static head should equal the elevation of the source of supply. As the static levels in the deep wells have a slope some movement is indicated. Such movement, however, is probably relatively small.

The natural conditions are changed when wells are drilled into such deeper strata and pumping occurs. The discharge creates velocities toward the wells which require a lowering of pressure to overcome the friction of the water movement. Such lessening of pressure may be marked during pumping with quick recovery when pumping ceases. Strata under pressure may recover their static level more quickly than surface strata, where actual filling in of the area depleted is required.

It is more difficult to secure observations on deep ground water than on shallow sources. Deep wells are necessarily expensive and in consequence are operated more nearly continuously. Idle wells for observational use are not usually available. Operating wells reflect the influence of their own drawdown rather than static levels.

In the Kings River area deep wells are relatively sensitive to draft. The stopping of flow in wells at a distance of over two miles when other wells are pumped has been observed. Such lowering is the result of lessened pressure due to the friction head required to produce the discharge of the pumped well. These conditions together with the effect of the present pumping from deep wells indicate that the amount of draft obtainable from deep wells in this area without excessive lowering is probably not as large as that obtainable in areas having favorable shallow ground water supplies.

GROUND WATER IN WEST SIDE AREA FROM TULARE LAKE TO MENDOTA.

This area covers the portion of the valley extending for about 50 miles along the west side of the north and south channels of Kings River. The width below the 300-foot contour varies generally from 6 to 8 miles, and includes a gross area of 250,000 acres.

No canal service is received within this area, the canals on the west side of the stream channels being within the area classed as the Valley Trough. Present development is entirely from deep wells.

Within the Mendota Irrigation District in the northern portion of the area 27 wells supplied 13,000 acres in 1925. These wells yield 2 to 3 second-feet each. They are from 1200 to 1500 feet deep and are perforated only below depths of 600 to 800 feet. The Boston Land Co., irrigates about 15,000 acres near Westhaven, of which about one-half is in trees and vines, and one-half in annual crops. Including other developments, such as those of the Kings County Development Co., west of Wheatville and near Murray, the total area now being supplied by pumps exceeds 30,000 acres or about one-eighth of the gross area.

It is difficult to secure readings on the ground water, as practically all wells are operated nearly continuously. No attempt has been made on Map No. 1 to draw ground water contours for this area. In Water Supply Paper 398 general ground water contours are shown. These were based on the shallow wells then available in 1907 and show a slope from the west toward the east as would be expected for waters derived from the west.

Such scattered records as are available indicate that the deep ground water probably had some slope from the west to the east, particularly in the southern portion of the area. Present records indicate varying amounts of change. Under pumping conditions, the slope appears to be from the east to the west. The available records do not fully show the amount of lowering that has occurred. Such records as are available indicate a material lowering in some portions of the area, the lowering being larger in the areas of heavier draft.

The quality of the water in this area has been discussed in Chapter II. The water from shallow wells is not available in sufficient quantity to furnish a good irrigation supply; by perforating only the deeper strata it is not used. The quality of the deeper water varies. These variations are not regular, but the water tends to be better in the southern part of the area than in the northern part.

The incompleteness of the available data makes any discussion of the ground water supply of this area unsatisfactory. The large cost of wells and the uncertainties of the supply, both as to quality and quantity, make development in this area hazardous. With only one-eighth of the gross area developed, lowering appears to be occurring. Whatever source of replenishment this area may have it is relatively distant. In other areas remote from sources of ground water supply, the ground water has been found to be sensitive to heavy draft. There is no reason to expect different results in this area. Development in this area should be undertaken only by those understanding the conditions and able to afford the risks involved.

GROUND WATER IN TULARE LAKE AREA.

This area covers the bed of Tulare Lake and adjacent low areas. It lies south of the area under the Kings County canals and west of the outer Kaweah and Tule areas. On the southwest the hills approach the lake area. The division between this area and the one to the south is made at the so-called Sand Ridge in township 24 south. The area of the Corcoran Irrigation District is included, although this is only partly within the area of Tulare Lake.

Tulare Lake receives the surplus run-off of the Kern, Tule and Kaweah rivers and such portions of the surplus run-off of Kings River as flows south. The area submerged varies widely. Before reclamation of the lake bed began, at high water stages about 300 square miles were submerged. Reclamation has been gradually extended by the construction of levees enclosing additional areas until nearly all of the lake bed is now more or less completely reclaimed. The last large inflow into the lake occurred in 1916. The larger part of the reclamation work has been accomplished since that date.

The surface soil of the lake bed is underlaid generally by a tight clay which prevents percolation into or out of the lake. The lake has been dry in recent years, due to the less than normal run-off that has occurred.

Over most of this area, ground water is obtainable only from deep wells. In Water Supply Paper 398 the ground water conditions in the eastern portion of the area were discussed. It was found that water from depths varying from 100 feet near Corcoran to 500 feet about 8 miles to the west was too highly alkaline to be suitable for use for irrigation. Water from wells from 1200 to 1800 feet deep near Corcoran was found to be suitable for irrigation. Deeper wells in the main lake area were not available at the time Water Supply Paper 398 was prepared

In discussing the change in quality of water from shallow wells between the delta areas to the east and the lake area, a line of division was shown between the areas in which the two types of water occur. The line passed through Lemoore, Corcoran and Angiola. This has come to be known locally as the "Mendenhall fault"—Mr. W. C. Mendenhall being the principal author of Water Supply Paper 398. This division was not described as a fault in the sense of being a line of movement but was the location of a change in quality of ground water. The difference was explained as being due to the difference in the nature of deposit of the materials, those to the west being lake deposits containing alkalis, due to the evaporation from the lake; and those to the east being delta deposits not subject to such factors. Deeper water from wells considered to come from depths below those resulting from lake conditions did not show such differences in quality. Wells less than 500 feet in depth are regarded as shallow wells in this area.

Until recently this shallow water has not been used to any extent. In those areas in which such water could be secured its quality frequently made its use undesirable. Ground water development was by deeper wells up to 2000 feet in depth from which both the quantity and quality were much better. The use of such deeper pumped water and of some canal supply in the Corcoran District has resulted in the establishment of a new source of supply for the shallow water table and some recent wells are now drawing on this source. Such shallow wells are supplied by the percolation losses from other uses. The available records do not show the extent of fluctuation that has occurred from the present draft on these wells. The amount of draft that can be supported would be expected to be limited to the amount of the percolation losses from other uses. As the canal supply is irregular and the deep wells are used on only a portion of the district area, the extent of draft which can be supported by the shallow ground water can not be expected to provide a permanent supply for a large area of additional land. To such extent as the shallow supply can support a pumping draft it represents a desirable reuse of other sources.

Deep wells have been used in the area of the Corcoran Irrigation District for considerable periods. Such wells were formerly artesian. Wells several miles to the east of this area also flowed until recently. As most of the deep wells are operated nearly continuously it is difficult to secure readings representing the standing level of the deeper ground water. General data indicate that the levels, while pumping, have lowered 30 to 50 feet in recent years. Recent development has been in the northern and eastern portion of the area.

In the northern portion of Tulare Lake wells of about 1800 feet depth are used. These wells are usually perforated below 600 feet depth and yield 2 to 3 second-feet. Such wells frequently contain gas. Analyses of water from four wells showed low sulphate content; indicating that their source is not from west side materials. The amount of bicarbonate and chloride was larger than desirable.

Wells in the southwestern portion of the lake have not encountered water in sufficient amount for irrigation. Wells are not in use in the southern portion. Some deep wells are in use in the southeastern part of the area. The Alpaugh Irrigation District conveys its main supply into its district from wells in the area to the south.

Pumping of deep wells south of Corcoran has been practiced longer than in other parts of the area. Wells 1300 to 2000 feet in depth are used giving discharges of about 3 second-feet. Ground water in this area now stands 30 to 60 feet below the surface in some wells which formerly flowed when not pumping. Present ground water is from 100 to 120 feet below the ground while pumping. The larger part of this lowering has occurred during the last four years.

CHAPTER IV.

GROUND WATER IN TULARE COUNTY AREAS.

This area includes the lands dependent on Kaweah and Tule rivers and Deer and White creeks. It is the same area covered by Bulletin 3 of the Division of Engineering and Irrigation published in 1922. The following discussion is based on the data collected in the preparation of Bulletin 3 and records that have been secured since its completion. The earlier observations include those begun in 1917 by the Lindsay-Strathmore Irrigation District over most of the Kaweah River area. These were extended to cover the whole county by this office beginning in 1920. Later observations of ground water over the whole area were made by the Division of Engineering and Irrigation in the fall of 1922 and 1924. Arrangements were made with Mr. C. H. Holley of Exeter, California, for the use of certain ground water records which he had secured in the course of his private practice over a large part of the territory covered by the Tulare County investigations of this office. These observations began in 1916 and have been continued to date, and have been made available for use in the preparation of this report. The conclusions stated in this report are based on the author's study of all of the records available to date in this area. About 550 wells were included in the earlier investigations and about 800 wells are being measured by Mr. Holley, the records covering periods beginning in 1917 to 1920 for different parts of the area. The available records are considered to furnish an adequate basis on which to determine the effect of pumping in this area. The obligation of this office to all of those who have assisted in making available ground water records is gratefully acknowledged.

Good yields are obtained from wells of relatively shallow depth in almost all parts of the Tulare County area. The depths are greater in the higher parts of the area adjacent to the foothills. As shown by the statistics of irrigation, ground water development has been active in nearly all parts of the area. In many instances the ability to secure satisfactory rates of discharge from wells has been accepted as an indication of an extensive and permanent source of supply. The ability to pump water from underlying materials depends on the coarseness of such materials and the ease with which they yield water. Such water may be drawn from the accumulations of long periods of time. A good discharge from a well does not of itself indicate any regular source of supply. Without adequate sources of supply, heavy pumping can only result in the gradual lowering of the ground water.

The ground water conditions in the different parts of Tulare County vary widely and a discussion of general or average conditions has little value. The direction of slope and elevation of the ground water are shown on Map No. 1; the depth to ground water on Map No. 2; and the lowering from 1920 to 1925 on Map No. 3. In the discussion the area has been divided into smaller areas representing differences in the conditions of ground water use and supply. These areas are the same as those used in Bulletin 3, the later records enabling the results of Bulletin 3 to be brought down to date.

GROUND WATER IN KAWEAH RIVER AREAS.

The conditions of water supply and use on the Kaweah River areas were discussed in detail in Bulletin No. 3, covering data available to the end of 1921.

The run-off of the Kaweah River at Three Rivers for the period 1890 to 1921 was estimated as an average of 438,000 acre-feet per year. The run-off for each year since 1921 has been as follows:

1921–22	461,000 acre-feet
1922–23	363,000 acre-feet
1923–24	102,000 acre-feet
1924–25	325,000 acre-feet

The addition of these four years to the period 1890 to 1921 results in an estimated mean annual run-off for the period 1890 to 1925 of 427,000 acre-feet. In addition there is some run-off, estimated as an average of 13,000 acre-feet per year, from the drainage area below Three Rivers, giving a total mean annual run-off of 440,000 acre-feet. Kaweah River is divided at McKay Point into the St. Johns and Kaweah channels. Diversions are made from both channels. Water entering the Kaweah Channel in excess of the diversions therefrom may reach Tulare Lake either through Cross Creek or by way of Elk Bayou and Tule River. Water flowing through St. Johns River without being diverted enters Cross Creek and may finally reach Tulare Lake.

The records of flow leaving the Kaweah Delta were analyzed in Bulletin 3 with the conclusion that such outflow under existing conditions of use would have averaged 55,000 acre-feet for the period 1890 to 1921. Practically no outflow has occurred since 1922. The estimated mean annual outflow for the period 1890 to 1925 becomes 50,000 acre-feet when the years since 1921 are included. Not all of such outflow would reach Tulare Lake as there are diversions on both channels between Tulare Lake and what is considered as the outer edge of Kaweah River Delta.

Several canals divert from both the St. Johns and the Kaweah channels. An analysis of the diversion records in Bulletin 3 indicated a usual total simultaneous diversion of about 1900 second-feet. Sustained run-off in excess of this amount was found to produce outflow from the delta. Lesser amounts of run-off produce outflow except in the main summer months.

The areas served by the different canals are, in some cases, overlapping and it is not possible to separate the areas served and the ground water supply for each canal. The area irrigated varies in different years with the extent of the stream flow. The usual area found to be irrigated by canals alone in 1921 was about 102,000 acres with an additional area of about 26,000 acres which received some canal irrigation and secured a supplemental supply by pumping. Similar data for 1925 have not been secured. There has not been much change in the total area of about 128,000 acres receiving some canal service except as the run-off has varied in each season. However, there has been a material increase in the proportion of this area which has been provided with facilities for pumping to supplement the canal supply. This increase in supplemental pumping is the result of the small run-off of recent years as well as the general tendency toward more complete utilization of the land.

Including lands receiving only pumping service it was estimated that the total area irrigated in 1920 which was dependent on Kaweah River for its water supply was 175,000 acres. The increase in this area since 1920 has not been large, although no complete statistics are available.

Ground Water.

Fairly complete records of the fluctuations of the ground water on the Kaweah Delta are available since early in 1917. These records cover all of the delta except the westerly portions lying beyond the areas served by canals. Records covering the westerly portion of the area were begun in 1920.

The extent of the stream flow entering and leaving the Kaweah Delta has been discussed. The surface stream flow of Kaweah River is considered to be the only source of water supply of material extent now reaching this area. Similarly the surface outflow is considered to be the only water leaving this area of material amount. The basis for this latter conclusion was discussed in detail in Bulletin 3. The ground water slopes in the adjacent Kings River areas indicate that outward ground water movement from the Kaweah River northward under the Kings River Ridge does not occur within the depths reached by existing wells. The ground water in the Kaweah Delta during the winter months of minimum use was found to rise by an amount which varies with the extent of the winter stream flow. If material outflow occurred, lowering of the ground water would result in such months of minimum supply. The material encountered in wells becomes finer toward the outer edges of the delta. The finer texture of the surface strata on the western portion of the delta would limit, if not entirely prevent, any movement in these strata. There have been no visible natural outlets for ground water movement into Tulare Lake as the lake becomes dry in years of deficient stream flow. All of these factors combine to support the conclusion that all of the run-off of Kaweah River absorbed within the Kaweah River Delta is available for use in the delta.

The Kaweah River area has been divided for purposes of discussion. The divisions are based on conditions of use and supply. The main area of the delta includes the area within which canal service is received, although only a portion of the total area actually receives such service. There are some canals which divert from Kaweah River and serve lands mainly above Venice Hills. The areas so served are segregated from the main canal area below Venice Hills. There is also an area considered to be a part of the Kaweah Delta which does not receive canal service. This is the outer or western portion of the delta. The area between the Lindsay-Strathmore Irrigation District and Elk Bayou, while not originally a part of the Kaweah Delta, may now receive ground water from the delta, due to the lowering of the water table within the area with a reversal of the natural ground water slope as shown on Map No. 1.

The general conditions for each of these four areas for 1921 are as follows:

Summary of Areas Irrigated and Pumping Draft for Kaweah River Areas in 1921.

Areas served only by canals are not included.

Area	*Gross area, acres*	*Areas Irrigated By canal and pumping*	*Areas Irrigated By pumping only*	*Total estimated net draft from ground water, acre-feet*	*Average draft in acre-feet, per acre. For area irrigated*	*Average draft in acre-feet, per acre. For gross area*
Main area of Kaweah Delta covered by canals diverting for lands below Venice Hills	190,000	18,900	37,400	85,000	1.5	0.45
Area covered by canals diverting mainly for lands above Venice Hills	60,000	6,900	9,700	27,000	1.6	0.45
Area of lower Kaweah Delta outside of areas covered by canals	95,000	100	14,900	31,000	2.1	0.30
Area west of Lindsay-Strathmore Irrigation District toward which ground water slopes from the Kaweah Delta	20,000	-----	7,300	19,000	2.6	0.85
Totals	365,000	25,900	69,300	162,000	1.7	0.45

The heaviest pumping draft occurs in the area west of the Lindsay-Strathmore District, where the sources of supply are the most indirect.

The following table summarizes the average ground water fluctuations for each of these areas for the period covered by the available records. The fluctuations for the lower delta area have been estimated for the first three years shown:

Summary of Average Fluctuations of Ground Water, in Feet, in Kaweah Delta Areas 1917-1925.

Area	*Average Fluctuation for Period 1917–1918*	*1918–1919*	*1919–1920*	*1920–1921*	*1921–1922*	*1922–1924*	*1924–1925*	*Total or Mean*
Main area of Kaweah Delta covered by canals diverting for lands below Venice Hills	—2.5	—2.1	—0.1	—0.8	+1.3	—7.0	—0.6	—11.8
Areas covered by canals diverting for lands mainly above Venice Hills	—0.9	—0.9	—0.2	—0.8	—0.25	—6.35	—1.0	—10.4
Area of lower Kaweah Delta outside of areas covered by canals	—3.2	—2.7	—1.3	—1.8	—0.25	—3.0	—3.7	—15.95
Area west of Lindsay - Strathmore Irrigation District toward which ground water slopes from the Kaweah River	—2.2	—2.1	—0.8	—1.3	—0.9	—9.3	—3.4	—20.0
Mean	—2.2	—2.0	—0.4	—1.0	+0.5	—6.0	—1.6	—12.7
Total run-off of Kaweah River, acre-feet	237,000	281,500	377,500	373,500	475,000	232,000	325,000	318,000
Rainfall at Visalia, inches	8.07	8.85	9.32	8.56	11.26	6.89	10.38	8.78
Estimated pumping draft, acre-feet	124,000	133,000	142,000	162,000	170,000	200,000	210,000	168,000

The seasons used end November 1. The fluctuations for 1923 and 1924 are combined, as readings were not secured in 1923. The run-off, rainfall and draft for the two years are the annual average in each case.

The figures presented in the preceding table represent the general results since 1917, but of themselves alone furnish little basis for conclusions regarding the relative draft and supply. The entire period of eight years contains but one year, 1922, in which the run-off equalled the mean and this year only exceeded the mean by less than 10 per cent. The ground water depletion that has occurred varied in the four different parts of the area as well as within the areas themselves.

For the eight years the ground water for the whole Kaweah Delta has averaged to lower 1.6 feet per year. The average run-off retained in the delta for the same period has been 78,000 acre-feet per year below the normal. The average lowering per year over the gross area of 365,000 acres would represent a depletion of 77,000 acre-feet per year of ground water storage if an average drainage factor of 12.5 per cent is assumed.

For 1925 a shortage in the supply retained within the delta of 65,000 acre-feet resulted in an average lowering of 1.6 feet. This lowering with a 12.5 per cent drainage factor represents 73,000 acre-feet for the gross area considered. This indicates that for the area as a whole the average water supply retained will about support the present acreage. The increase in pumping plants in recent years has been largely for supplemental pumping on lands receiving canal irrigation. Dut to the lowering of the ground water natural subirrigation no longer occurs and artificial subirrigation or pumping is now required. Such pumping has not increased the actual draft on the gdound water as compared with past use with high water table, to the same extent as pumping for new areas would increase the draft.

The areas within which the ground water rose in 1922 and 1925 are shown on Map No. 3. Any area showing a rise in 1925 would be expected to fully maintain its ground water during a series of normal years. The area showing a rise in 1922 would also be expected to similarly maintain its ground water except for the marginal parts of the area.

The conclusion would appear justified that with average run-off in the Kaweah River the water supply will support the existing development if it can be distributed so as to reach all parts of the area. Any material increase in area will be expected to result in a deficiency in supply even in a period of normal years with resulting gradual ground water lowering. This statement concerning average conditions should not be interpreted to mean that the ground water will be maintained in all parts of the delta with present development and normal run-off, as the present distribution of use is such that many parts of the area do not receive the supply needed locally even in normal years. The occurrence of a series of normal years can be expected to restore the ground water within the area receiving direct canal service. Such areas would be expected to recover the full lowering of the past eight years with resulting conditions of high water table before recovery is shown in the outer or more heavily pumped areas. Such local conditions can best be discussed by individual areas.

The results in the Kaweah Delta appear to furnish an answer to the question of whether greater or less lowering of the ground water will occur at the outer edges of a delta than near its apex under conditions of pumping draft which exceed the supply. The ground water in a delta occurs on a slope from the apex toward the outer edges. The argument has been made that with heavy pumping resulting in ground water depletion, the ground water would be drained out from the apex more rapidly than from the edges so that there would be less lowering in the outer areas. This argument does not find support in the Kaweah Delta records. The maximum lowering has occurred in those areas near the outer and lower edges of the delta wherever heavy pumping has been practiced with little local canal service while areas near the upper portion of the delta where replenishment occurs by percolation from the stream channel and canal use have shown only a small lowering.

MAIN AREA OF KAWEAH DELTA COVERED BY CANALS DIVERTING FOR LANDS BELOW VENICE HILLS.

This area represents about one-half of the gross area of the Kaweah Delta. It includes nearly all of the areas receiving canal service and over half of the area receiving pumping supplies. Due to the distribution of the diversions from the Kaweah River over this area, it shows a more quick recovery of its ground water than areas not so supplied. Within the area the relative proportions irrigated by canals and by pumping varies so that differences in the response to the stream flow are quite marked. Increase in pumping since 1921 has been mainly to supplement canal use rather than as an entire source of supply. The number of plants increased 20 per cent from 1924 to 1925.

Map No. 3 shows the total ground water lowering that has occurred from 1920 to 1925. Occasional areas having favorable priority of canal rights and receiving good supplies even in dry years, show no lowering even during this period of less than normal run-off. In general the line of five-foot lowering encloses the areas receiving canal service of regular character Pumping in such areas is less extensively developed and canal use more nearly meets crop needs. Any portion of the Kaweah Delta which has not lowered more than 5 feet during the past 5 years of below normal run-off would be expected to fully maintain its ground water under existing conditions of development in years of normal supply.

The lines of 10 feet or larger lowering of the ground water during this period represents the outer portions of the area where a small percentage of the gross area receives canal service, or where the late priority of the canal results in wider variations in the supplies received in different years. The diversions of such canals as the Packwood and Tulare Irrigation District fluctuate widely in different years. Deficiencies in canal supplies are overcome by larger amounts of pumping. Wide fluctuations of the ground water in such areas are to be expected. Lowering in years of below normal run-off may not indicate an overdraft if it is balanced by the rise in the years of above normal run-off.

There has only been one year of normal supply in the period 1920 to 1925. In 1922 the ground water rose over practically this entire area, the rise being as large as 6 feet in the area of largest previous lowering near Tulare. Even with this gain in 1922, the total change for the past 5 years in this local area has been a lowering of 15 to 20 feet. The supply in 1922 was less than 10 per cent above normal for the whole river; the diversions of the Tulare Irrigation District exceeded its average by more than this amount, however. The diversions by the Tulare District in 1922 were larger than the total diversions for the three years 1923 to 1925.

Hydrographs of typical wells are shown in Fig. 15. Well L–2 is located about 4 miles east of Visalia along upper Deep Creek in an area which receives adequate canal service. The ground water in 1925 was as high as in 1921. A quick response to the diversion of water into Deep Creek and adjacent canals is shown. The ground water is fully maintained in this area under existing conditions. In years of more than normal run-off the ground water may rise sufficiently close to the surface to cause injury.

Wells M–22 and M–16 show the contrast between areas receiving regular canal service and those receiving service only in years of large run-off. Well M–22 is located 3 miles east of Tulare in an area served by the Farmers Ditch. The run-off in 1922 which was only about 10 per cent above normal nearly restored the accumulated lowering from 1917 to 1921. The ground water held its elevation in 1925. In this area no lowering of the ground water over a series of years is to be anticipated under a continuation of present conditions. Well M–16 is located four and a half miles west of Well M–22, in the pumping area west of Tulare. Lowering is shown in all years except 1922. In 1922 the Tulare Irrigation District secured sufficient diversion for the irrigation of some lands in this vicinity. The lowering of 1920 and 1921 was more than recovered in 1922. The lack of canal supply and the heavy pumping resulting in a lowering of about 20 feet in the 3 years from 1922 to 1925. Well M–16 illustrates the dependence of the ground water on direct local supplies. The ground water less than 5 miles to the east, as illustrated by Well M–22 has shown a total lowering of only 3 feet from 1922 to 1925, during which the run-off of Kaweah River has averaged only 60 per cent of normal. The supply received around Well M–22 has not enabled Well M–16 to maintain its level. Well M–16 is only maintained when canal water is brought into its own area. The future fluctuations of Well M–16 will depend on the amount of canal water that may be diverted into its vicinity.

Well N–11 is about 7 miles west of Tulare, near the end of Packwood Creek and at the west edge of most of the pumping in this vicinity. The ground water held its own in 1922. In other years it lowered. A larger lowering occurred in 1925 in proportion to the run-off in Kaweah River than in previous years. This reflects the greater tendency to lower in this area with the increased draft of recent years. The canal diversions into this area are limited and it

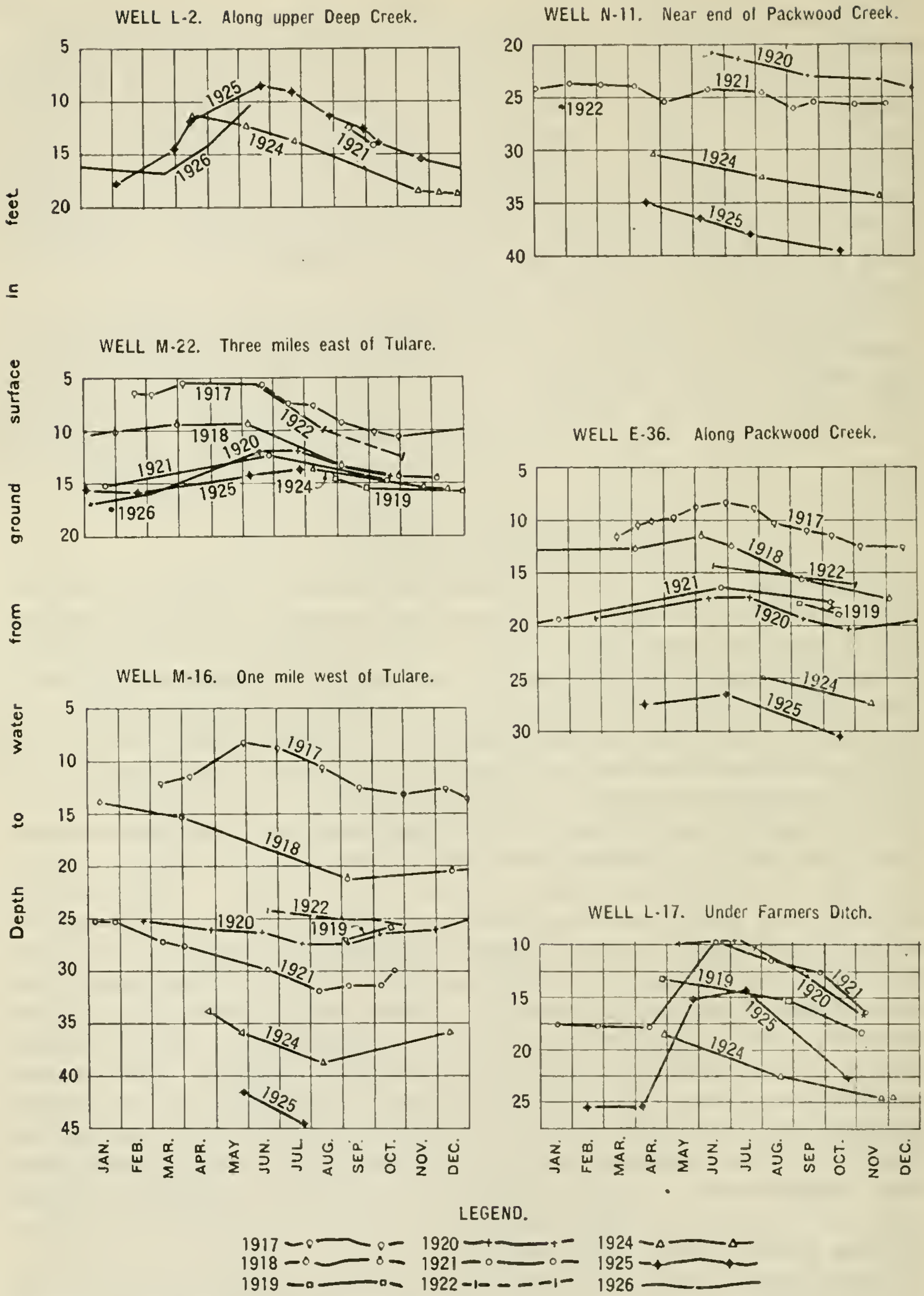


FIG. 15. Hydrographs of typical wells in main area of Kaweah Delta.

does not appear probable that they will be sufficient even in a series of years of average run-off to maintain the ground water under the existing draft.

Well E–36 is also along Packwood Creek. It is near the Southern Pacific Railroad between Tulare and Goshen and at the general division between the areas receiving canal service and those depending mainly on pumping. The ground water rose in 1921 and 1922, but has lowered in all other years. The total lowering from 1920 to 1925 was 10 feet as compared to 17 feet in Well N–11. This again illustrates the helpful effect of adjacent canal irrigation, as the pumping draft just west of Well E–36 is heavier than that around Well N–11.

Well L–17 is 4 miles east of Tulare and 2 miles east of Well M–22 and is within the canal irrigated area. It also illustrates the effect of canal service. No canal water reached the vicinity of this well in 1924, and a continual lowering occurred. In 1925 the canal flow resulted in a rise of over 10 feet during the period of canal use and a net rise for the year of about 2 feet.

The records for the entire area of the Tulare Irrigation District show the following comparison between the diversions by the district and the ground water fluctuations:

Season	*Total diversions in acre-feet*	*Average fluctuation of ground water in feet*
1920–21	28,600	—1.9
1921–22	59,600	+2.4
1922–23	31,100	—2.6
1923–24	700	—7.4
1924–25	20,000	—4.65

The diversion in 1922 was sufficient to result in an average rise over the entire district of 2.4 feet. More lowering occurred in 1923 than in 1921 with a slightly larger diversion in the latter year. This probably reflects the effect of the increase in draft. Of the total diversions only part reaches the lands within the district, the conveyance losses being heavy. Apparently an annual diversion of about 45,000 acre-feet is needed to maintain the ground water within this district. Improvements in conveyance will reduce the diversion required.

The records seem to justify the conclusion that in years of normal or above normal run-off, present development will not result in a ground water depletion for the main area of the Kaweah Delta covered by canals diverting for lands below Venice Hills as a whole. The average rise in the ground water in 1922 within this area of 1.3 feet will about account for the excess supply of that year. In normal years the ground water in the areas under the canals having earlier rights will rise and in a series of wet years will probably again approach nearer to the surface than may be desirable. For the outer areas, the extent to which the ground water may recover losses in dry years by the gains in wet years will depend on the extent to which actual diversion into such areas occurs. The whole showing of the ground water records in this area emphasizes the necessity for bringing surface supplies into each part of the area if the ground water is to be maintained. The support of the ground water in all marginal portions of this area depends on the diversions into such areas rather than the filling of the delta as a whole. The ground water may rise in the upper portions of the delta until drainage is needed without causing a rise in the outer areas not receiving canal supplies.

Only 55 per cent of the gross acreage in the main Kaweah area is now irrigated. The preceding conclusions apply only for this extent of development. If all or any considerable part of the remaining 85,000 acres not irrigated should be placed under irrigation the present relations of the supply and draft would be changed and the conclusions stated would no longer apply.

AREAS COVERED BY CANALS DIVERTING FOR LANDS MAINLY ABOVE VENICE HILLS.

The area considered under this heading is shown on Map No. 1. The division lines are not definite, but the area includes the lands whose ground water appears to be derived from the Kaweah River above Venice Hills or from canals diverting from the upper portions of the river.

Near both the St. Johns and Kaweah channels some areas are subirrigated. Little pumping for local use is practiced on these lower lands. The pumping plants of the Lindsay-Strathmore Irrigation District are located in this area; the water pumped is used within the district near Lindsay and Strathmore.

For the whole area, the area receiving pump service increased 25 per cent from 1921 to 1924. The number of pumping plants increased 10 per cent from 1924 to 1925.

The ground water contours on Map No. 1 show a slope of the ground water into the northern part of this area from above Venice Hills between the hills and Cottonwood Creek. For the four years, 1917 to 1921, an average lowering of 3.6 feet occurred. A lowering of from 1 to 4 feet occurred in 1922 and 3 to 5 feet from 1922 to 1924. Records for 1925 in this area are less complete. A lowering of over 10 feet from 1920 to 1925 has occurred in parts of this area. The present draft appears to exceed the supply now reaching this portion of the area and continued lowering is to be anticipated.

Well B–54, Fig. 16, is north of the main Kaweah Delta in an area of scattered pumping. A continued gradual lowering is shown. No gain was shown in 1922. This well appears to be located sufficiently far away from streams or canals so that it is but slightly affected by the character of the season. The slower rate of lowering appears to be due to the small draft in its vicinity rather than to a dependable ground water supply.

On the south side of the river the larger pumping area is in the southeastern part of township 18 south, range 25 east. Some irrigation from canals is received. Yokohl Creek also crosses the area. From 1917 to 1921 an average lowering of 13 feet occurred under an area of 3000 acres of the heavier pumping. The drop in 1921 for the same area averaged nearly 4 feet. From 1920 to 1925 a total lowering of about 15 feet occurred. The development is relatively complete in this area, 2460 acres of the gross area of 3000 acres being irrigated in 1921. The present rate of draft exceeds present sources of supply and continued lowering is to be anticipated.

AREA WEST OF LINDSAY-STRATHMORE IRRIGATION DISTRICT TOWARD WHICH GROUND WATER SLOPES FROM THE KAWEAH DELTA.

This area covers the portion of the cone of depression brought about by local pumping which has a slope from the Kaweah Delta as shown on Map No. 1. The portion sloping from the Tule River areas has been separately discussed. The area in the Lindsay-Strathmore District is not included.

The present direction of the ground water slope as shown on Map No. 1 in this area is the reverse of that existing prior to pumping. The pumping has resulted in such extensive lowering that the ground water slopes into the area from all directions.

From 1920 to 1925 the average lowering has been 20 feet. There has been a relatively small increase in the development during this period. Lowering has occurred in all years. The pumping occurs mainly in the northern end near Exeter and in the southern portion west of Lindsay. The northern portion is nearer areas using Kaweah River water and the lowering has not been as large as in the southern portion.

Well K–8, Fig. 16, is located between the two main areas of pumping at the north and at the south ends of this area. Continual lowering is shown, amounting to 11 feet from 1920 to 1925. This is a less amount of lowering than that in the areas of heavier pumping to the north or to the south. Well K–8 is about 3 miles east of Outside Creek. The ground water held its level in 1922.

Well R–23 is within the Lindsay-Strathmore Irrigation District. Its fluctuation reflects the history of the water supply of this area. Pumping occurred in 1917 with a resulting heavy lowering. The use of district water in 1918, 1919, and 1920 resulted in a recovery of nearly all the lowering in 1917. Further pumping since 1920 has resulted in a total lowering of about 40 feet. This well illustrates the inability of the local ground water to support pumping draft.

For the whole area, from November 1 to February 1, of the seasons 1917 to 1921, the ground water rose an average of about 3 feet, or at the rate of 1 foot per month. This rise appears to be larger than that for the remainder of the year, as rates of draft of 1 acre-foot per acre of gross area have resulted in lowering of 2 feet per year.

The total lowering to date exceeds 80 feet in some parts of this area. The greatest lowering has occurred within five miles of areas along Outside Creek that have lowered less than 5 feet in the deficient years from 1921 to 1925. Even with this excessive lowering ground water movements do not appear to have been established which will supply the present draft. The average lowering in 1925 was greater than that in either 1918 or 1919, although the stream flow was larger in 1925 than in either 1918 or 1919. The more rapid lowering in recent years may be partially the result of resuming pumping from wells in the Lindsay-Strathmore District to the east, which were not operated in 1917 and 1918.

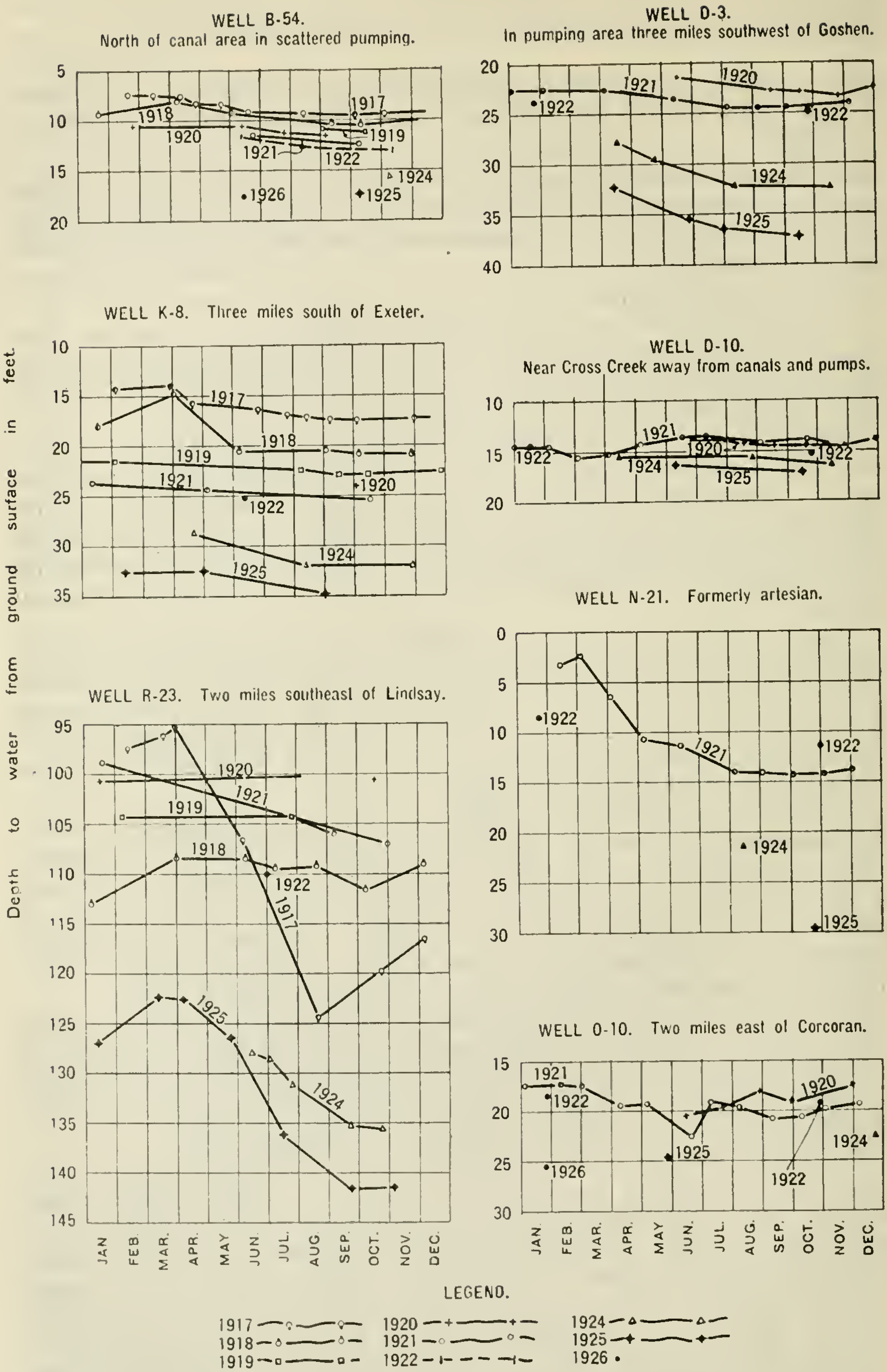


FIG. 16. Hydrographs of typical wells in outer areas of Kaweah Delta.

The records available in this area indicate that no practicable extent of lowering can be expected to result in sufficient ground water movement into the area to maintain the ground water. Present draft appears to exceed the ground water supply and continued lowering can only be expected under present conditions.

GROUND WATER IN AREA OF LOWER KAWEAH DELTA OUTSIDE OF AREAS COVERED BY CANALS.

This area is a part of the general Kaweah Delta in that both the ground water and the ground surface slopes continue into the area from the main delta. There is no direct irrigation within the area, except for a small area near Cross Creek. The pumping development is scattered; in 1921 only about 15 per cent of the gross area was irrigated. The area increased slowly until 1925 when a number of new wells were placed in operation, particularly in the southern part of the area.

The lowering in this area appears to be proportional to the draft, in the different parts of this area, as shown by the following table:

Township and range	*Average pumping draft in acre-feet per acre of gross area in 1921*	*Average lowering of ground water in feet* 1921	1922	1925
T. 18 S., R. 23 E.	0.5	1.2	.4	1.9
T. 19 S., R. 23 E.	0.5	1.3	.9	2.9
T. 20 S., R. 23 E.	0.9	3.2	.6	6.5
T. 21 S., R. 23 E.	0.2	1.7	1.0	3.5

In T. 20, S., R. 23 E., in 1921 and in 1925 larger lowering occurred than in the other areas. In 1922 an area of rice irrigated in 1921 was not irrigated. The increase in pumping in 1925 is reflected in the ground water. T. 21 S., R. 23 E., with a small draft in 1921 lowered more than the two northern townships. The distance from streams or canals is greater in the southern portion of the area and greater sensitiveness to draft is to be expected.

Lowering occurred over this entire area in 1922 except for small areas adjacent to the main delta area. A lowering of from 1 to 10 feet occurred generally in 1925, the largest lowering occurring in areas of heaviest draft.

Well D–3, Fig. 16, is located in an area of considerable pumping southwest of Goshen. Canal service of irregular character is received by lands about 1 mile east of this well. Little change occurred from 1920 to 1922, but rapid lowering has occurred since 1922. The lowering in 1925 was much larger in comparison with that from 1920 to 1922 than can be accounted for by the difference in stream flow and indicates the effect of the increase in the rate of pumping since 1922. Continued lowering with present draft even in years of normal run-off is to be expected in this well.

Well D–10 is near Cross Creek and west of the areas irrigated by pumping. Very little fluctuation is shown. This well is not materially affected by either draft or supply. Pumping draft 3 or 4 miles away has not caused much lowering. Flow in Cross Creek does not cause any material rise. This area would not appear to offer promise of ability to supply any large rate of draft.

Well N–21 was formerly artesian. In 1908 it discharged sufficient water to irrigate crops and also operated a hydraulic ram for pumping into a tank. It has been lowering rapidly in recent years. The rate of lowering appears to be increasing. As this well reflects variations in pressure, its lowering may be caused by draft either to the east or to the west. It illustrates the similar effect on deep wells as on shallow ones of the increase in the use of ground water in recent years.

Well O–10 is a shallow well 2 miles east of Corcoran. Little fluctuation occurred from 1920 to 1922. Some increase in the rate of lowering is shown since 1922. Shallow wells have not been used very largely for irrigation in this area, although some use is now being made of such wells to the west.

With the increase in development since 1922, the recurrence of years of normal run-off will be expected to result in lowering over this entire area. Only continued lowering can be anticipated in this area as its distance from direct sources of replenishment prevents its receiving a sufficient supply to maintain the present draft. Any further increase in use can only be expected to increase the rate of lowering and shorten the time when the increased lift will result in pumping being no longer profitable.

GROUND WATER IN AREA IN LINDSAY-STRATHMORE IRRIGATION DISTRICT.

This district includes about 15,000 acres near the eastern edge of the valley between Kaweah and Tule rivers. It is too far from the areas irrigated from either stream to have received ground water from such sources. The locally tributary drainage area has a very limited run-off. Pumping for citrus orchards began about twenty years ago. Such pumping resulted in a lowering of the ground water. By 1915 the water secured from some wells had become too alkaline for use without injury to the trees. Outside sources of supply were sought, the irrigation district organized and a system securing water by pumping from areas along Kaweah River constructed. The substitution of the new source of supply for local pumping resulted in recovery of the ground water in some wells. In recent years some pumping from wells within the district has been resumed. The resulting ground water conditions vary in different parts of the district due to local factors of use. The experience in this area fully demonstrates the inadequacy of its local sources of ground water within the district to maintain the draft required for the area now developed.

GROUND WATER IN AREAS DEPENDENT ON TULE RIVER FOR THEIR WATER SUPPLY.

The area dependent on Tule River for such water supply as it may receive extends on the north to the center of the cone of ground water depression produced by the pumping west of Lindsay and to the Kaweah River areas; to the west to the area considered to represent the general mingled ground waters of the San Joaquin Valley trough; to the south to the Deer Creek area and to the east to the line of contact of the granite and the valley fill or to the area considered to be dependent on Lewis Creek. A portion of this area is served by canals diverting from Tule River. Such replenishment as the remainder of the area may receive is indirect by general ground water movement. The boundaries of the area are indefinite and there is probably little effect from Tule River on the ground water of the outer portions of the area.

In 1921 63,700 acres were found to be irrigated within this area. Of this area about 2800 acres depended entirely on canal service for their water supply; and 14,000 acres received both canal and pumping service; the remaining area depended entirely on pumping. There has been little change in the area served by canals since 1921, except as this varies from year to year with the extent of the run-off.

For the whole area, there was little change from 1921 to 1924 in the area served by pumps. Some decrease in area occurred particularly in the irrigation of pasture. In 1925 an increase of about 4500 acres occurred due mainly to the irrigation of additional areas of cotton.

Run-off of Tule River.

The run-off of Tule River was discussed in detail in Bulletin 3. The sum of the run-off of the main Tule River and the South Fork for the period 1890 to 1921 was estimated to be an average of 137,000 acre-feet per year. The discharge for the years since 1920 has been as follows:

1920–21	90,500 acre-feet
1921–22	141,600 acre-feet
1922–23	102,200 acre-feet
1923–24	26,600 acre-feet
1924–25	87,000 acre-feet

The records for the South Fork are not complete for these years. Missing records have been estimated by comparison with the main Tule River. The addition of the last four years to the period 1890 to 1921 results in an estimated mean annual run-off for the period from 1890 to 1925 of 132,000 acre-feet.

Diversions by Canals.

Available canal diversion records were discussed in Bulletin 3. Continuous records of the diversions are not maintained. Except in years of large stream flow, practically all run-off is diverted. There has been no outflow in Tule River since 1921. It is estimated that outflow occurred in eleven of the last 36 years, the average amount being 15,000 acre-feet per year for the entire period.

As there has been no outflow during the years covered by the ground water observations, the run-off of Tule River represents the water supply available for this period. The available data does not permit the diversions to be estimated for different parts of the area served by canals so that it is treated as a whole.

7—47076

Ground Water Fluctuations.

The average ground water fluctuations for the whole area are shown in the following table:

Division of area	*Per cent of gross area irrigated in 1921*	*Ground water fluctuations in feet* Nov. 1920 to Nov. 1921	Nov. 1921 to Nov. 1922	Nov. 1922 to Nov. 1924	Nov. 1924 to Nov. 1925	Nov. 1920 to Nov. 1925
North Tule	44	—3.0	—0.7	—11.4	—1.0	—19.1
Main Tule	38	—1.5	+1.5	— 7.7	—0.9	— 9.0
South Tule	12	—1.75	—0.45	— 4.2	—1.6	— 8.0
Outer Tule	21	—1.8	—1.2	— 5.9	—3.0	—11.9
Whole Area	31	—1.8	—0.25	— 7.1	—2.3	—11.45
Run-off of Tule River in acre-feet		90,500	141,600	64,400	87,000	

The above table shows wide variations in the fluctuations for the different areas and years. These variations reflect the conditions in each area. It is necessary to discuss the ground water conditions separately for such divisions of the area.

GROUND WATER IN MAIN TULE RIVER AREA INCLUDING THE AREAS WITHIN WHICH SOME LANDS RECEIVE CANAL IRRIGATION FROM TULE RIVER.

This area includes all lands receiving any irrigation from Tule River except those below the junction of Elk Bayou and Tule River. In some years excess flow in Tule River may reach areas adjacent to Tulare Lake; this has not occurred in the years covered by the ground water records.

The principal irrigation from Tule River occurs in the upper portion of the area from Porterville to Woodville. The canals in the lower portion of the area receive only irregular service. The data have been divided into three areas representing the upper, middle and lower portions.

In 1921 the areas irrigated were canvassed and data on the pumping draft secured with the following results:

	Gross area, acres	*Area irrigated entirely or partly by pumping, acres*	*Estimated gross draft, acre-feet*	*Per cent of gross area irrigated*	*Estimated draft, acre-feet per acre of gross area*	*irrigated area*
Upper lands east of west line of Range 27 East	26,200	8,365	20,900	32	0.80	2.5
Lands in Range 26 East	28,800	11,167	21,100	39	.75	1.9
Lands west of Range 26 East	21,800	6,623	10,400	30	.50	1.6
Totals	76,800	26,155	52,400	34	0.7	2.0
Additional area receiving only canal service		2,805				
		28,960		38		

In the upper area orchards, mainly citrus, were the more extensive crop, with alfalfa grown on the next largest area. In the middle area there were less trees but more vines, with a larger area in alfalfa than in any other crop. Alfalfa and pasture predominated in the western portion. In 1924 the total area receiving pump service had increased only slightly, the increases and decreases in different parts of the area nearly balancing. In 1925 there was an increase of about 1700 acres.

The fluctuations of the ground water for the five years, 1921 to 1925, are as follows:

Year	*Average fluctuations of the ground water in feet* Upper portion	Middle portion	Western portion
1921	—.35	—1.20	—3.30
1922	—.2	+2.0	+1.25
1923–1924	—6.7	—9.0	—7.5
1925	+2.3	—2.2	—2.6
Totals	—4.95	—10.4	—12.15

In the upper area Tule River and Porter Slough as well as the diversions by canals result in a more direct recharge of the ground water with a consequent smaller lowering. Even with the below normal run-off of 1925, the ground water rose over nearly all of this area. The records indicate that with normal run-off this upper area as a whole will maintain its ground water with present development. However, while this statement is considered to be correct for the area as a whole, it will not apply to all parts of the area. Heavy pumping in local areas not receiving canal supply would be expected to result in progressive lowering.

In the middle area the increase in the area supplied by pumping since 1921 resulted in a greater lowering in 1925 than in 1921 with about the same run-off in Tule River. A sufficient proportion of the larger run-off in 1922 reached these lands to result in a rise over nearly the entire area. The lowering in 1923 and 1924 exceeded that in other portions of the Main Tule area. The lands receiving canal service are distributed over nearly all of this area. The present rate of pumping draft is larger than in the upper area. The available records do not cover years of normal run-off under present rates of draft, so that the effect of normal run-off is difficult to predict. The lowering in 1925 probably represents a ground water depletion of about 12,000 acre-feet. The run-off in 1925 was about 50,000 acre-feet below normal. This area should receive one-fourth or more of the difference between the run-off in 1925 and the normal run-off so that the ground water would be expected to be maintained in a normal year. It would appear that the present draft can be supported by this area without continued ground water lowering, the gains of normal or wet years balancing the losses of dry years. However, any material increase in draft would probably result in progressive lowering particularly in the portions not receiving direct canal service.

In the western area, the fluctuations in different years are less consistent. Less lowering occurred in 1925 than in 1921. A rise occurred in 1922. Diversions into this area have been very small in the years shown except in 1922. The increased lift has tended to decrease the draft which probably explains the decreased lowering in 1925 as compared to 1921. Judged by 1922, normal run-off should maintain the ground water in this area. The maintenance of the ground water will be dependent on the actual flow of the river and diversion by canals within the area rather than by general ground water movement into the area. In 1921 with very little stream flow or diversion within this area, the draft can be accounted for by the ground water lower-

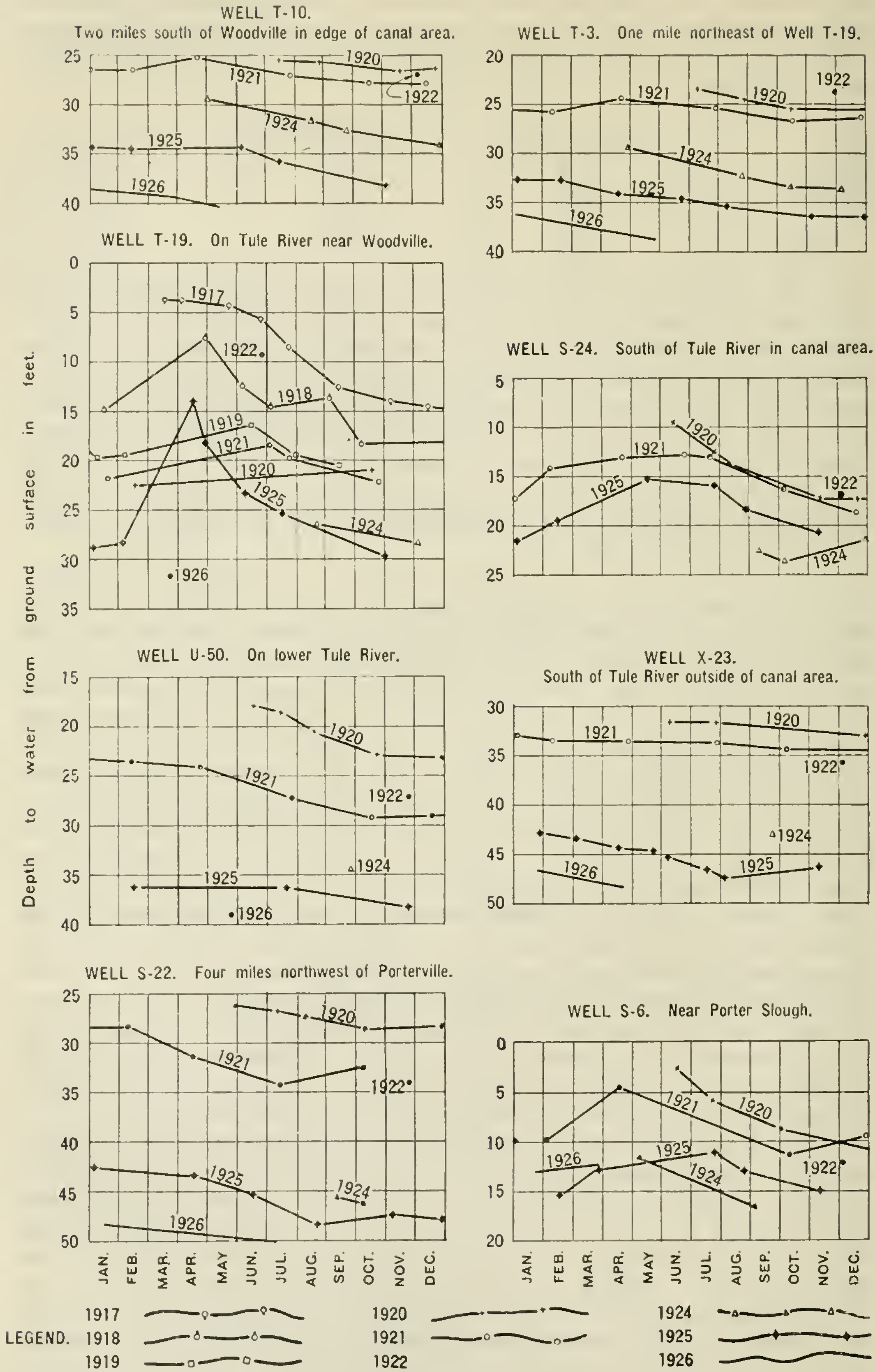


FIG. 17. Hydrographs of typical wells in Main Tule River Area.

ing. The same is true in 1925. In 1922 only 10 per cent of the run-off of Tule River would need to reach this area in order to supply the draft and account for the ground water rise that occurred. These general comparisons indicate that no large item for movement of ground water into the area is required in order to account for the fluctuations. Such movement, if it occurs, would occur slowly and would represent only a limited quantity per year. These results are another illustration of the dependence of ground water on direct and local sources of supply rather than on distant movements.

Hydrographs of typical wells are shown in Fig. 17. Well S–6 is near Porter Slough and canal irrigation in the area west of Porterville. It recovered the lowering of 1924 in 1925. In years of normal run-off this well would be expected to fully maintain its level. Well T–19 is the same as Well 1331 of the Lindsay-Strathmore Irrigation District, so that records since 1917 are available. It is located on Tule River in the middle portion of the Main Tule area. In 1917 normal run-off resulted in a high ground water level in this well. Lowering occurred in the following dry years to 1922 when nearly all of the loss was recovered. Larger lowering occurred in 1923 and 1924 with some net loss in 1925 and 1926. In April, 1925, a short flow occurred in Tule River at this well which resulted in a marked rise. The amount of this flow was not sufficient, however, to maintain this gain and there was a small net lowering in 1925. With normal run-off this well would be expected to recover its former levels.

Well U–50 is along Tule River in the lower portion of the Main Tule River area. It recovered in 1922 but has lowered continuously since. Recovery is to be expected in any years in which flow in Tule River reaches this portion of the river. Over a series of years of average run-off this well would be expected to maintain its level.

Well S–22 is located in the northern part of the upper portion of the Main Tule area. Canal irrigation is received to the east of this well. Lowering has occurred in each year covered by the records. The normal run-off in 1922 resulted in small lowering. This well should hold its level in years of above normal supply but would not be expected to gain sufficiently in such years to balance the lowering in subnormal years and a continual lowering is to be anticipated.

Well T–3 is 1 mile northeast of Well T–19. Continuous lowering has occurred except in 1922. The rise shown by Well T–19 in April, 1925, did not reach Well T–3. Unless pumping draft is too greatly increased, this well would be expected to maintain its levels over a series of normal years.

Wells S–24, X–23 and T–10 are all located south of Tule River and illustrate the difference in lowering that results from varying conditions of canal supply. Well S–24 is about 1 mile south of the river and under the Poplar Ditch. It rose in 1922 and showed a relatively small lowering in 1923 and 1924. The supply in the Poplar Ditch in 1925 resulted in a rise over 1924. No permanent lowering is to be expected in this well. Well X–23 is three miles southeast of Poplar and away from canal irrigated lands. It did not gain in either 1922 or 1925 and has lowered 15 feet in the five years from 1920 to 1925. Continued lowering in this well is to be expected even in years of normal run-off. Well T–10 is in the southern portion of the area receiving canal service south of Woodville. A small gain was shown in 1922. No recovery occurred in 1925. In normal years this well would probably maintain its level, although the increase in pumping since 1922 may have changed the conditions then existing. Over a series of years having average run-off in Tule River this well would be expected to show some continued lowering.

GROUND WATER IN AREA ON NORTH OF TULE RIVER DELTA.

The area toward which the ground water now slopes from Tule River, as shown on Map No. 1, differs from that toward which the ground water sloped prior to pumping due to the cone of depression that has been caused by the pumping draft. The development began prior to 1912. A total of 10,530 acres out of a gross area of 23,700 acres were irrigated in 1921. This represents a development of nearly one-half the gross area. The area irrigated increased to 11,900 acres in 1924. As there are no direct stream supplies or canal use in this area, such a large proportion of development would be expected to result in rapid depletion of the ground water.

Ground water observations were begun in this area in 1917 by the Lindsay-Strathmore Irrigation District. The average results for all years of observation are shown in the following table:

Season ending Nov. 1 of	*Mean lowering of the ground water*	*Mean rise of ground water from Nov. 1 to Feb. 1 of year listed*	*Run-off of Tule River, total acre-feet*	*Rainfall at Porterville, inches*
1917	4.6		120,100	11.65
1918	3.9	1.3	50,900	8.12
1919	3.5	1.9	76,400	10.25
1920	3.1	2.7	111,800	10.67
1921	3.0	3.4	90,500	9.49
1922	.7		141,600	13.32
1923				8.36
1924	11.4		64,400	5.27
1925	4.0	1.5	87,000	12.00
Total or mean	34.2			10.06 (long time mean)

A tendency toward a larger recovery during the winter season was shown in the earlier years. The observations since 1921 have not been sufficiently frequent to determine the amount of winter recovery except for 1924–25, in which fifteen wells recovered an average of 1.5 feet. Although the ground water slope into this area was steeper in the winter of 1924–25 than in the earlier winters, there does not appear to be any greater recovery due to such steeper gradient. As the winter of 1924–25 was one of irregular rainfall with more pumping than is usually practiced, further records are required before positive conclusions can be drawn.

The lowering in 1925 was larger than in 1918, 1919, or 1921, although the run-off was similar or larger in 1925 than in these earlier years. The only year having normal run-off, 1922, showed a lowering. The larger rainfall in 1922 probably reduced the pumping draft. These records and comparisons indicate that a general average lowering of about 4 feet per year can be anticipated in this area and that the lowering will tend to be more uniform from year to year than the run-off of Tule River.

Well P–15, Fig. 18, is located in the southwestern portion of this area, about 5 miles from Outside Creek on the Kaweah Delta and one and one-half miles from Well T–3, Fig. 17, in the Tule River area. It is more favorably situated in relation to these sources of supply than the average for this area. Material lowering has occurred in all years since 1917, except 1922. While some recovery may occur in years of excess run-off, such recovery can not be expected to equal the lowering in years of less than normal supply and progressive lowering under existing conditions is to be expected at this well. Well Q–13 is located near the north side of this area and about in the center of the cone of depression. Only records for 1924 to 1926 are available. These show a material lowering in each of these years.

GROUND WATER IN SOUTH TULE AREA.

This area includes 7000 acres lying south of the area reached by canals diverting from Tule River and north of the area that may be affected by Deer Creek. Only 860 acres or 12 per cent of the area was irrigated in 1921. In 1924 the area irrigated had increased to 1130 acres. Practically all the development is in the eastern portion of the area and consists of citrus orchards.

The ground water has lowered less in the last five years than in any other outer area adjacent to Tule River. The amount of the lowering increases from the north to the south

The gross draft in 1921 was estimated as 2780 acre-feet or an average of 3.35 acre-feet per acre irrigated. Some of this probably returned to the ground water. If the net draft is assumed to be 2 acre-feet per acre or 1720 acre-feet per year, the average lowering over the gross area would supply the full draft without any inflow if the drainage factor is 15 per cent. Continued lowering in this area is to be anticipated. Unless the area irrigated is increased, however, the average rate of lowering to be expected will require a relatively long period before the costs of pumping become excessive for the present crop. The smaller rate of lowering appears to be due more to the small proportion of the area which is developed than to any direct source of ground water supply.

Well Y–3, Fig. 18, is located in the center of this area and west of the pumping area. The lowering shows a tendency to increase in amount; with a similar amount of run-off in Tule River in 1921 and 1925, a lowering of two feet occurred in 1925 as compared with no lowering in 1921.

GROUND WATER IN OUTER TULE RIVER AREA.

This area lies southwesterly from the area which receives irrigation from canals diverting from Tule River. The data have been divided so as to show the results in the eastern and western portions separately, this division being made on the west line of range 25 east. The eastern portion covers the part of the Tule River Delta from Pixley to Tipton, extending eastward to the area covered by canals.

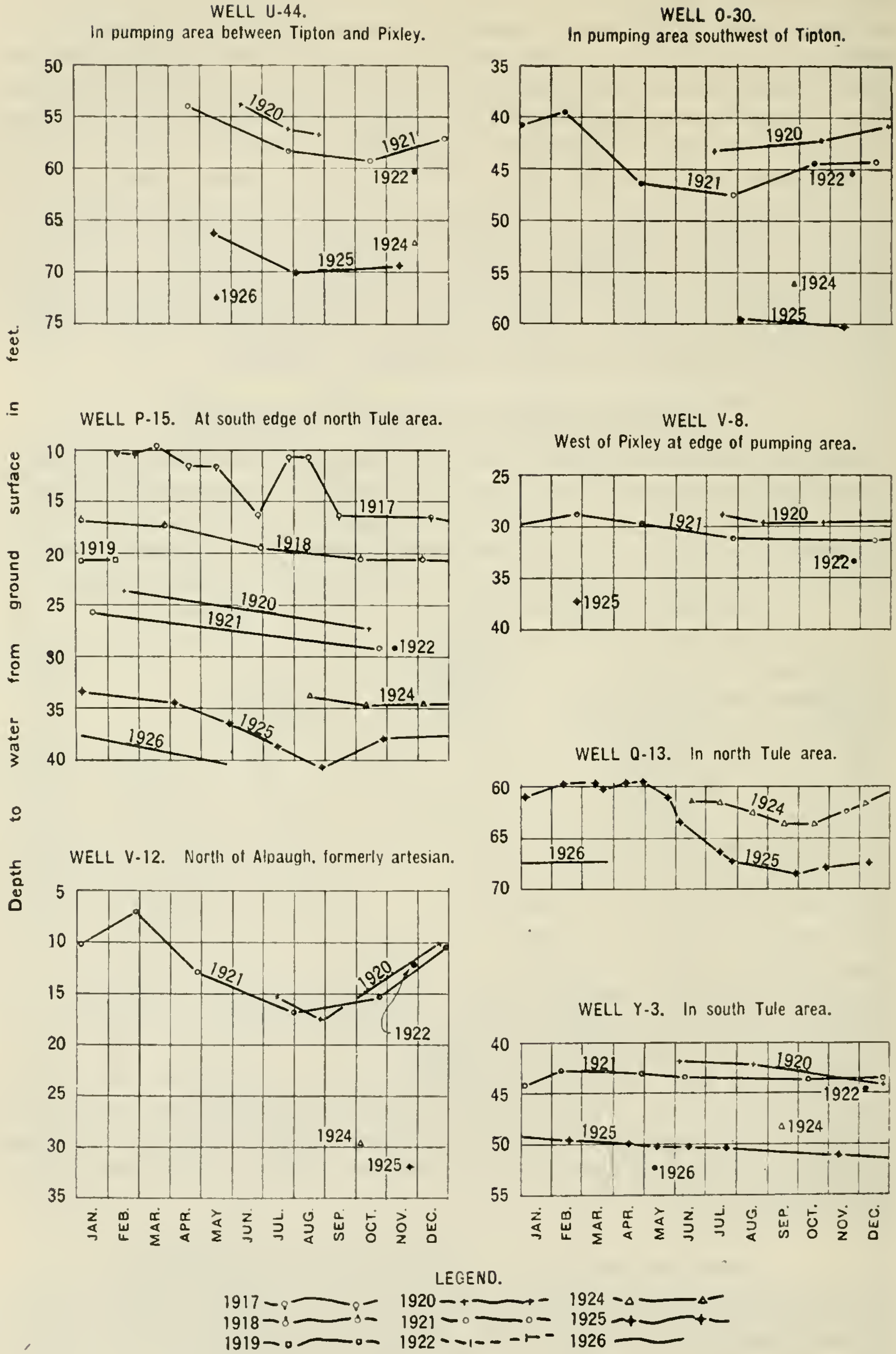


FIG. 18. Hydrographs of typical wells in Outer Tule River Area.

The western portion includes the area which may receive its ground water supply from Tule River sources, but which is situated relatively distant from any channel or canals supplied by Tule River. The western boundary of the area is the division between ground water derived from Tule River and that derived from general mingled sources and is necessarily indefinite.

The canvass of pumping in these two areas in 1921 gave the following results:

	Total area irrigated, acres	Gross area, acres	Estimated gross draft, acre-feet	Per cent of gross area irrigated	Estimated draft, acre-feet per acre of gross area	Estimated draft, acre-feet per acre of irrigated area
Eastern portion	12,366	40,400	31,660	31	.80	2.55
Western portion	10,988	56,300	20,480	20	.35	1.85
Totals	23,354	96,700	52,140	24	.55	2.25

In 1921 the development in the eastern portion consisted largely of alfalfa with a marked increase of vines in the preceding year. In the western portion alfalfa and pasture were the main crops with only small areas of orchards or vines. In 1924 the area irrigated had decreased about 10 per cent from the area in 1921, due mainly to the decrease in the area of pasture. In 1925 the area increased so as to slightly exceed that of 1921.

The average fluctuations of the ground water during the five years, 1921 to 1925, have been as follows:

Year	Average lowering of the ground water in feet — Eastern portion	Western portion
1921	2.25	1.55
1922	1.4	1.0
1923–24	6.0	5.85
1925	3.5	2.1
Totals	13.15	10.50

As in the case of other Tule River areas, a larger lowering occurred in 1925 than in 1921, although the run-off of Tule River was practically the same in these two years. Lowering occurred in 1922 with a run-off slightly above normal.

The rate of draft on the eastern portion of the area in 1921 was similar to that on the upper area receiving canal service, the lowering was six times as large as in the canal areas. In the western portion the rate of draft was less than half of that in the upper canal-served area, the lowering was over four times as large as in the canal area. These comparisons show the greater sensitiveness to draft of outlying areas not directly supplied by surface flow and demonstrate the much smaller rate of draft which such distant areas can maintain without continued lowering of the ground water.

In 1921, information was secured from the owners of fifteen wells covering the fluctuations in the preceding 5 to 15 years. The lowering varied from 14 to 29 feet and averaged 21 feet. The larger number of the wells were in the western portion of the area. For five of the wells in the eastern portion of the area the lowering varied from 17 to 25 feet.

Hydrographs of typical wells in this area are shown in Fig. 18. Well U–44 is located in the pumping area extending from Tipton to

Pixley. Continued lowering is shown. The lowering has been fairly uniform per year, being about the same in 1922 with above average run-off in Tule River as in the other years of less than average run-off. Well V–8 is about 4 miles southwest of Well U–44 and west of the main pumping area. Less fluctuation is shown.

Well V–12 is two miles south of Well V–8. It was formerly artesian, but stood over 30 feet below the ground surface in November, 1925. From 1920 to 1922 little actual lowering occurred, the cycle of fluctuation corresponding to that usually shown by wells in pressure strata with a reduction of pressure during the summer season of draft and a winter recovery. Conditions of increased draft since 1922 have resulted in a lowering of about 30 feet from 1922 to 1925.

Well O–30 is southwest from Tipton in the pumping area. This is a shallow well and shows continued lowering, although the amount of such lowering is less than in the deeper well, V–12.

The wells in the western portion of this area were formerly largely artesian. Wells which formerly flowed have not flowed for several years, some slight flow may occur during the winter months of minimum pumping draft.

The present estimated draft in this whole area is about 48,000 acre-feet per year or about 35 per cent of the mean annual run-off of Tule River. The ground water slopes from the main Tule River area, but the rate of slope and character of the material are not such as to indicate the movement of any such large proportion of the Tule River supply into this area. The extent of use and the ground water fluctuations indicate that nearly all the Tule River supply is retained and used within the main Tule River area.

The ground water lowering from 1921 to 1925 represents the drainage of a soil volume of 1,140,000 acre-feet. The total net draft at 2.0 area-feet per acre for the same five-year period would be about 235,000 acre-feet. If the drainage factor is assumed to be 12.5 per cent based on data from other similar areas, the ground water lowering would account for 140,000 acre-feet, leaving a total of 95,000 acre-feet or 19,000 acre-feet per year to be supplied by ground water movement into the area. While such a comparison is necessarily open to uncertainty in its numerical items, the general result appears reasonable. It is doubtful if a ground water movement of more than 20,000 acre-feet per year into this area occurs. This is less than half the average draft for the past five years.

The ground water in this area is only indirectly affected by the annual variations in the run-off of Tule River. More lowering has occurred in dry years than in seasons of larger run-off. However, the years of larger run-off are also years of larger local rainfall. Increased rainfall tends to decrease the draft due to the smaller amount of irrigation applied. The ground water is at too great a depth for direct penetration of rainfall to the water table to occur.

The continuation of the present pumping draft in this area can only be expected to result in an average ground water lowering of about 2 feet per year, even with average rainfall and run-off. In dry years larger lowering is to be expected; even in wet years some lowering is to be anticipated.

GROUND WATER IN DEER CREEK AREA.

This area includes those lands which appear to be dependent on the run-off of Deer Creek for such surface and ground waters as may be available. It lies between the Tule River and White Creek areas, and extends from the foothills to the general mingled ground water of the San Joaquin Valley. Like other areas its boundaries are not definite and some mingling of the ground water from adjacent sources may occur in the outer portions.

The estimated mean annual run-off of Deer Creek is 19,000 acre-feet as previously discussed. This with the run-off of such lower hill areas as are tributary to this area, estimated as not to exceed 1000 acre-feet, gives a mean annual water supply of 20,000 acre-feet. There is some direct use of Deer Creek for irrigation, but much the larger portion of the run-off reaches the ground water.

Including the area irrigated in the Terra Bella Irrigation District, a total of 15,500 acres were found to be irrigated in 1921. The area irrigated in the Terra Bella District increased from 3840 acres in 1921 to 4680 in 1925. The area irrigated in 1924, including that served by the Terra Bella District, is estimated to be 19,000 acres, or an increase of about 20 per cent since 1921. The area irrigated in 1924 represents only 18 per cent of the gross area of 106,000 acres.

The delivery in the Terra Bella District has averaged 1.5 acre-feet per acre cropped. The use on citrus orchards has varied from 1.75 to 2.0 acre-feet per acre. Under individual pumping plants where the wells were able to supply larger quantities, the average amount pumped was found to be about 3.0 acre-feet per acre in 1921.

The following table shows the relation of the lowering to the run-off of Deer Creek. Observations of the ground water were not made in 1923, so that it is necessary to combine the seasons of 1923 and 1924. The run-off of Deer Creek is taken from measurements by the Terra Bella Irrigation District:

Period	*Average lowering of the ground water in feet*	*Run-off of Deer creek, total acre feet*
November, 1920, to November, 1921	1.9	11,440
November, 1921, to November, 1922	.95	16,480
November, 1922, to November, 1924	4.6	*9,360
November, 1924, to November, 1925	2.4	17,240
Entire period November, 1920, to November, 1925	9.85	*12,780

* Mean annual run-off for the period.

The lowering for 1921, 1922 and 1923–24 is inversely proportional to the run-off of Deer Creek. The effect of the increasing draft is shown by a comparison of 1922 with 1925. Although there was a larger run-off in 1925 than in 1922, an average lowering of 2.4 feet occurred in 1925 as compared with 0.95 feet in 1922. The average lowering in 1923 and 1924 was practically the same as that in 1925, although the run-off in 1925 was nearly twice as large as the average for 1923 and 1924. As the run-off in 1925 was nearly normal, an average lowering of about 2.5 feet per year can be expected under present conditions of draft in this area, even in years of average run-off. Only a small area along the upper course of Deer Creek rose in 1925.

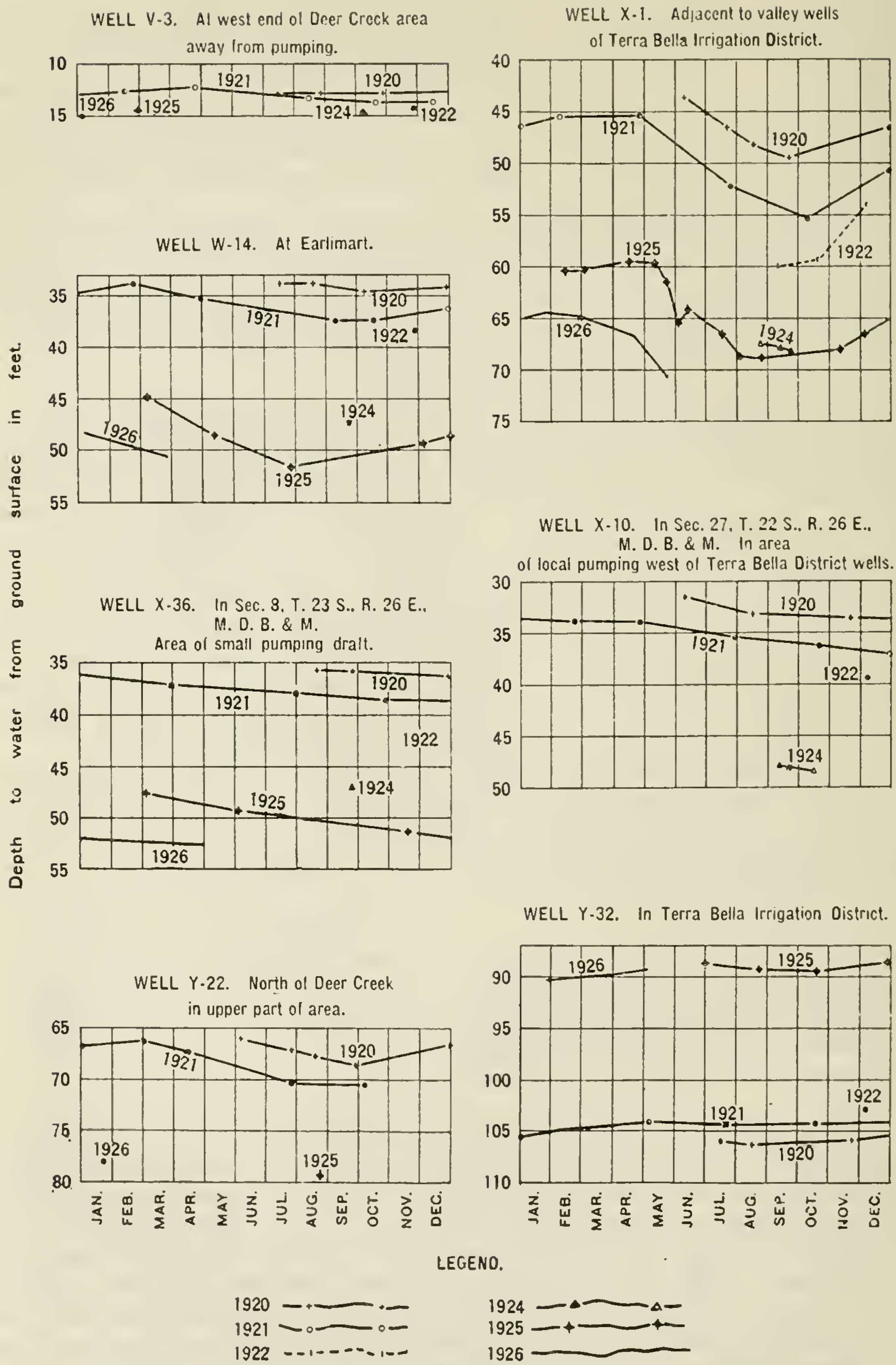


FIG. 19. Hydrographs of typical wells in Deer Creek Area.

The total draft for the whole area was estimated to be 35,000 acre-feet in 1921. This was obtained by a canvass of each individual pumping plant in which data on its discharge and period of operation were obtained as definitely as the variable field conditions would permit. This includes the draft by the Terra Bella District. The draft of the Terra Bella District increased from 5816 acres in 1921 to 6843 acre-feet in 1925. The draft by individual plants in 1925 is estimated to have increased to about 35,000 acre-feet. The estimated draft in 1921 was over twice the run-off for that year and over 50 per cent in excess of the estimated mean annual run-off available for these areas. In 1925 the draft had increased to twice the mean annual run-off.

Hydrographs of typical wells are shown in Fig. 19. Well V–3 is at the western end of the area and remote from pumping draft. Little effect of draft or of variations in replenishment is shown. Well W–14 at Earlimart is of similar depth. It reflects the heavy pumping draft in this area. Lowering in each year occurred amounting to a total of 17 feet for the five-year period. Well X–36 is near the course of Deer Creek in the center of the area between the area of pumping by the Terra Bella Irrigation District and the area between Earlimart and Pixley. A steady lowering is shown which has not varied materially with the run-off of the different years.

Well Y–22 is located north of Deer Creek adjacent to the pumping area near the edge of the valley. Continued lowering is shown.

Well X–1 is adjacent to the valley wells of the Terra Bella Irrigation District. The effect of the summer draft and winter recovery is shown. About 20 feet lowering has occurred in the five-year period. Well X–10 is shown 3 miles west of the Terra Bella District wells. Lowering is shown without the marked seasonal fluctuations shown by Well X–1.

Well Y–32 is within the Terra Bella Irrigation District. The water supply for this district is secured from outside sources. A rise of 16 feet has occurred in the five-year period. As there is very little pumping within the district, this rise reflects the ground water received from the irrigation by outside supplies and the local run-off. Wells at the western edge of the Terra Bella District have not shown a similar rise.

The largest lowering has occurred along Deer Creek in the vicinity of the pumping by the Terra Bella District as shown on Map No. 3, amounting to as much as 20 feet for the five-year period in parts of this area. A total lowering of about 20 feet has also occurred in the area extending from Earlimart to Pixley.

Wells east of the west line of range 27 east showed an average lowering of only 0.6 foot in 1925. Some wells along Deer Creek rose. In range 26 east an average lowering of 3.2 feet occurred. In the western part of the area in ranges 24 and 25 east the lowering average 3.1 feet. At the western edge of the area where pumping draft is light and the mingled ground water of the valley trough is approached only very small lowering occurred.

The records in this area, similarly to those for other areas without large sources of local water supply, illustrate the sensitiveness of the ground water to pumping. In the portions of the area in which there is little pumping, only limited lowering has occurred even during the last five years of deficient rainfall. Heavy lowering has occurred in all areas of heavy pumping. The lowering is due to such draft rather than to deficiencies in run-off. A continuation of such lowering can only be expected if the present rate of draft is maintained. Lowering is to be expected in some parts of the area even in years of excess run-off.

Present development represents only about one-fifth of the gross area and results in an overdraft on the available ground water supply. The attempt to irrigate additional areas of the 85,000 acres in this area not now developed can only increase the rate of ground water lowering and decrease the time until pumping may no longer be profitable. Any increase in pumping from the local sources of ground water is against the interests of those now using such sources in this area.

GROUND WATER IN WHITE CREEK AREA.

This area extends from the Deer Creek area on the north to the Kern County line on the south. The western boundary has been taken at about the line of the Santa Fe Railroad. The boundaries do not represent definite divisions between sources of supply. The area represents the apparent general limits within which recharge of the ground water from White Creek may occur based on the ground water contours as shown on Map No. 1. Further west the ground water blends into the mingled sources of ground water supply of the general valley trough.

Wells of good yield are secured in nearly all parts of this area. The depth of the ground water increases toward the upper or eastern side of the area. Irrigation wells in the main portion of the area were formerly about 200 feet in depth. Present practice is to install wells of about twice this depth in order to secure larger rates of discharge. As discussed in the following pages, such greater depths of wells do not make available any new sources of ground water supply but merely add to the area adjacent to the well through which the same sources of supply may be secured at a more rapid rate.

The total mean annual run-off of White Creek has been previously estimated as 6300 acre-feet. This occurs irregularly and varies in different years from an almost negligible amount to several times the average. The run-off has been below normal in recent years. The larger part of the run-off appears to be absorbed in the upper channel which has been cut through the older sediments and may be one of the sources of the artesian supplies of the lower valley area. Surface run-off in recent years has reached the valley area only in limited amounts. In 1926 heavy local storms produced a temporary run-off that exceeded that occurring in any of the other years covered by the observations of ground water.

The gross area is 104,000 acres. The acreage irrigated is available for 1921, 1924 and 1925. Ground water fluctuations are available for the last five years. The results are as follows:

Period November 1 to November 1	*Area Irrigated, acres*	*Mean lowering of ground water in feet*	*Rainfall at Porterville, per cent of normal*	*Per cent of gross area irrigated*
1920–21	11,575	1.3	95	11
1921–22	-----	1.1	133	--
1922–24*	15,950	5.9	68	15
1924–25	19,700	3.7	120	19
Total for 5 years		12.0		

* Crop area for 1924. Total lowering for 2-year period and average annual rainfall are used.

The irrigated area increased 70 per cent from 1921 to 1925. In 1925 the area was 25 per cent larger than in 1924, due mainly to the planting of cotton. The lowering of the ground water in the different years has varied with the amount of use rather than with the rainfall. In 1925 with a larger rainfall, the average lowering was about three times that in 1921. The lowering in the years 1923 and 1924, including the very dry year of 1924, was less per year than that in 1925.

The available data indicate an average gross pumping draft of nearly 3 acre-feet per year per acre of crop. Based on comparisons with other areas a net draft of about 2 acre-feet per acre would be expected, although it is doubtful if pumping has been practiced on much of the area long enough to result in the downward movement of excess moisture reaching the ground water.

The draft on the ground water was estimated as 27,000 acre-feet in 1921. The total draft for the five-year period, 1921 to 1925, has probably been about 175,000 acre-feet. The total run-off of White Creek for the same period has probably not exceeded 20,000 acre-feet. The remaining draft could be supplied from the lowering of the ground water over the gross area that has occurred with a drainage factor of 12.5 per cent. This is about the value of the drainage factor found for the similar Shafter, Wasco and McFarland area and indicates that nearly all of the pumping draft has been supplied by ground water lowering within the area rather than by replenishment from outside sources. The deficiency in the run-off of White Creek during this period amounts to less than 10 per cent of this draft.

The pumping draft in 1925 was nearly 50,000 acre-feet, the estimated mean annual run-off of White Creek is about one-eighth of this amount. With only one-fifth of the area under irrigation giving a draft eight times the estimated available supply, it is not difficult to forecast the future course of the ground water in this area if the present rate of draft is maintained.

The preceding discussion has been based on average fluctuations for the whole area. The pumping development is not evenly distributed. The main irrigated area extends eastward from the line between Delano and Earlimart. The lowering here has been much larger than the average as shown on Map No. 3. To the west the lowering has

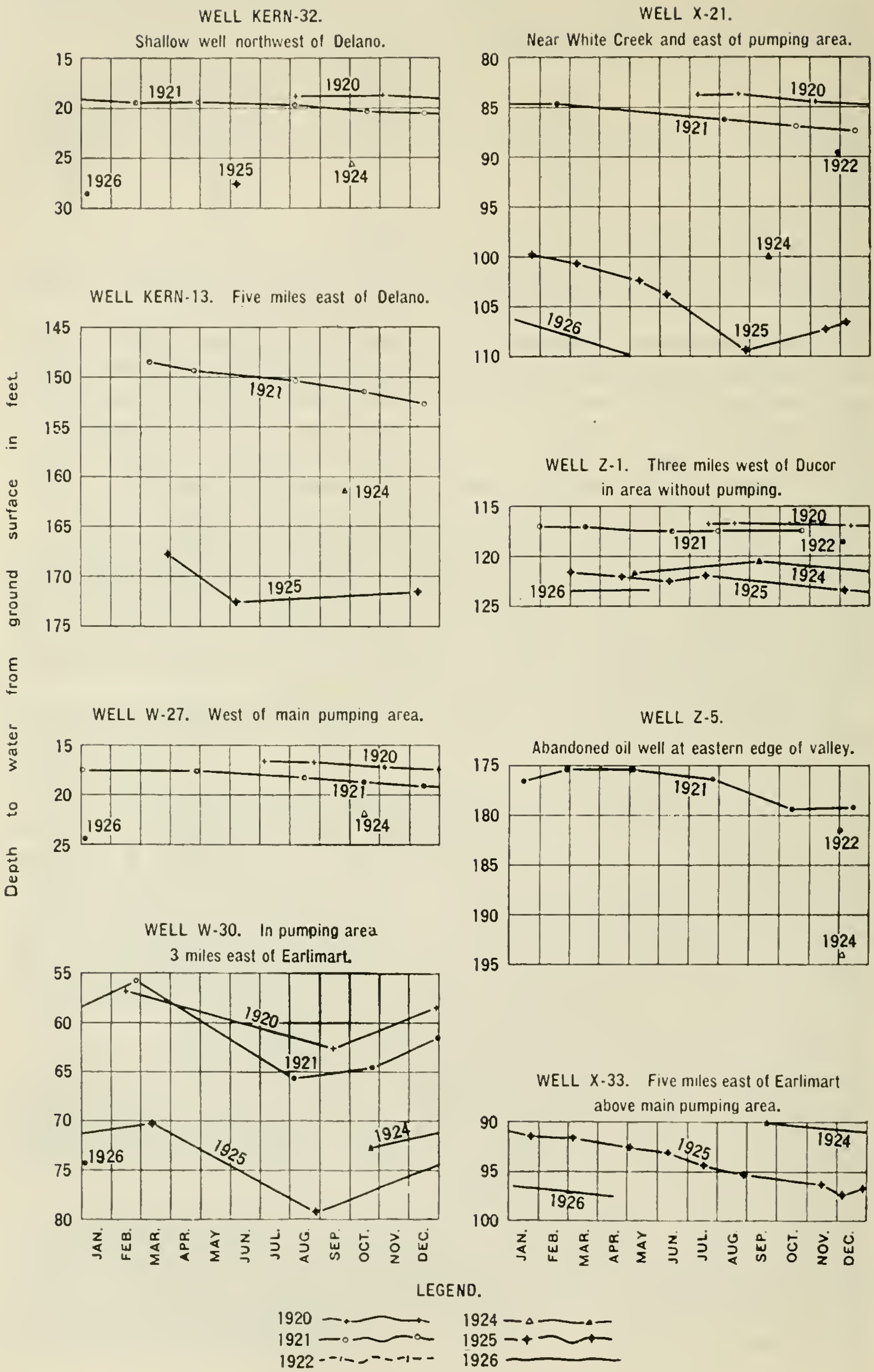


FIG. 20. Hydrographs of typical wells in White Creek Area.

been much less. East of the main pumping area in township 24 south, range 27 east, the area irrigated is more scattered and the lowering, while greater than that west of the main area, is less than that in the more heavily pumped portion.

Hydrographs of typical wells are shown in Fig. 20. Well W–27 is west of the pumping area. Lowering has occurred in all years, although the amount is much less than that to the east in the pumping area as shown by Well W–30. Well W–27 shows little fluctuation during each season. A gradual but continuous lowering has occurred in each year. Well W–30 shows the effect of the heavy local draft during the summer with the recovery during the winter season. The lowering in all years has exceeded the recovery; the net lowering has averaged over 3 feet per year. The recovery shown begins as soon as pumping is reduced in the fall and represents ground water adjustments between the areas heavily pumped and those of lighter draft rather than any outside source of supply. This is shown by well X–21, which is 2 miles further east and along the course of White Creek. Well X–21 continued to drop in 1920 and 1921 after Well W–30 had begun to rise. Well X–21 showed recovery in the latter part of 1925. This followed larger lowering during the early part of 1925 and reflects the increase in pumping near Well X–21 between 1921 and 1925.

Well Z–1 is located in an area of very little draft. It shows similar fluctuations to Well W–27 west of the area of pumping. A slow but continuous lowering occurred in Well Z–1. These four wells illustrate the difference in fluctuations due to pumping draft. Wells W–27 and Z–1 outside of pumping areas have lowered less than 10 feet from 1920 to 1925. Wells W–30 and X–21 within or near pumping areas have lowered 16 to 26 feet. The lowering in wells W–27 and Z–1 is probably largely due to the pumping rather than the deficient run-off of these years, as they showed about the same amount of lowering in the very dry year of 1924 as in the other seasons. These comparisons indicate that the lowering that has occurred is the result of pumping rather than of the less than normal rainfall for this period.

Well Z–5 is an abandoned oil well in section 34, township 24 south, range 27 east. It is deeper than the irrigation wells but shows similar lowering. Well X–33 was drilled for irrigation in 1920, water standing at 80 feet. It has not been used, but a lowering of 17 feet has occurred. This well is to the east of the main pumping area adjacent to Earlimart.

There has been discussion in this area as to whether the irrigation wells 400 to 500 feet deep would show the same character of fluctuation as the shallow wells. Wells W–27, W–30, X–21 and Z–1 are not as deep as the irrigation wells now being more generally used. Wells Z–5 and X–33 represent deeper wells. Another well, X–46, in section 30, township 24 south, range 26 east, 1200 feet deep, had water at a depth of 112 feet when drilled in April, 1925. The water stood at a depth of 124 feet in February, 1926, the plant being idle at the time of reading.

In Bulletin 3, prepared in 1922, the following statement was made: "The conditions existing in this area should make it obvious that only limited pumping drafts can be made without serious lowering of the ground water. The distance from any dependable source of recharge and the sensitiveness of the ground water to draft as shown by the 1921 records, make it evident that pumping in this area is drawing mainly on reserve of ground water which has been accumulated over an indefinitely long period. When once depleted by pumping, a similarly long period will be required for the refilling of the ground water storage. A continuation of the present rate of draft can only be expected to result in the lowering of the ground water to depths from which pumping will no longer be profitable. Every effort should be made to discourage additional development in this area, as it can only lessen the period of time before this condition occurs."

The additional records that have become available since the above quotation was written have served to emphasize the statements made. More favorable seasons of rainfall can not be expected to result in any material change in the rate of lowering. A continuation of the present rate of draft can only result in a continuation of the ground water lowering.

If the present extent of development has resulted in the conditions described, any increase in development can only shorten the time when the extent of lowering will so increase the resulting pumping lift that pumping will not be profitable. The interests of those now pumping will be best served by discouraging additional development and by limiting the draft to the amounts of water required under careful practice.

CHAPTER V.

GROUND WATER IN KERN COUNTY AREAS.

Ground water conditions in areas adjacent to Kern River were discussed in Bulletin 9 of the State Department of Engineering based on investigations made during 1920. Ground water observations have also been made by the Kern County Land Company and since its organization by the Kern River Water Storage District. These records are fairly complete for the period 1920 to date. Less extensive records have also been furnished by other owners. The availability of this material has enabled a much more complete analysis of the ground water conditions in this area to be made than would have otherwise been possible within the limitations of time available in the preparation of this report. The great assistance received from all of these agencies is gratefully acknowledged.

Rates of Pumping Draft.

In 1920 and in 1924–25 the area irrigated by pumping and the amount of draft were secured by a canvass of all pumping plants. The pumping draft was secured by direct measurement where feasible, by power consumption, lift and estimated or measured efficiency, or based on general data. The resulting estimates are considered to be fairly representative of the actual draft and to exceed the draft rather than the reverse.

For the Shafter, Wasco and McFarland areas, the 1920 results gave an estimated average draft of 3.3 acre-feet per acre. The corresponding figure for 1925 was 4.0 acre-feet per acre. In 1920 an average draft of 3.0 acre-feet was found for lands above the East Side Canal. In 1925 the draft under the East Side Canal is reported as 3.7 acre-feet per acre. Both of these results are in excess of the water requirements of similar crops as determined from canal practice and materially exceed the consumptive use found under similar conditions in other areas. While the figures may be somewhat liberal, it is thought that approximately these amounts were actually pumped.

These figures, as well as those in other areas, indicate the relatively heavy rate of pumping usually practiced where ground water is available at any time its use is desired. These results do not mean that all of the water used is utilized by the crops as losses occur under pump irrigation similar to those under canal practice. Seepage from farm canals occurs. With pumping plants on each farm the length of conveyance is relatively small but the rate of loss may be large due to the small stream. Material losses may occur from earth reservoirs. The percolation losses from the field applications are also large where heavy irrigations are applied.

The estimated draft given is considered to be representative of the water removed from the ground but is not regarded as representative of the actual ground water depletion. Such permanent depletion will be represented by the plant transpiration and the evaporation only, which for the conditions prevailing in these areas will be much less than the figures given for gross draft. The amounts of the consumptive use as indicated by records for areas where the available data permits of its separate determination are discussed elsewhere. The gross draft may also be the net draft in the earlier years of pumping until the downward movement of moisture losses has become sufficient in amount to reach and join the ground water. When this has occured, pumping in excess of moisture use by transpiration and evaporation represents merely a circulation of ground water rather than a consumption.

In 1920 a total area of 58,250 acres was served by pumping plants in Kern County. In 1925, this had increased to 100,000 acres, or an increase of over 50 per cent in five years. The largest increase in the area served by pumping occurred in the Shafter, Wasco and McFarland area and southeast of Bakersfield, both above and below the East Side Canal.

The United States Census of 1910 reports 6387 acres as supplied by pumps or flowing wells in Kern County. The report of the California Conservation Commission for 1912 gives 12,240 acres supplied by ground water. The area in 1920 was nearly five times that in 1912. The observations of the effects of this rapidly increasing draft on the ground water enable the limitations of the ground water supply to be discussed with more detail than would be possible with less development. As in other general valley areas such discussion can be more conveniently arranged by subdivision of the area into smallar parts.

The ground water contours for the entire area are shown on Map No. 1. These show the direction of slope of the ground water. Ground water movement occurs mainly at right angles to the ground water contours. Map No. 2 shows the depths to ground water. These represent the ground water without drawdown while pumping. The actual pumping lift will exceed the depths shown on Map No. 2 by the amount of the drawdown. The amount of the drawdown varies with the coarseness of the materials and the rate of draft. In most parts of this area good discharges are secured with a drawdown not exceeding about 20 feet. In some areas drawdown of twice this amount may occur under large draft. Map No. 3 shows the amount of lowering of the ground water that has occurred from 1920 to 1925.

GROUND WATER IN AREA ABOVE THE EAST SIDE CANAL.

This area includes all land above the area covered by the East Side Canal area. It includes all development from Edison to Arvin and Rock Pile. Ground water is the only source of water supply.

Caliente Creek is the only stream of consequence tributary to this area. In Bulletin 9, based on data available in 1920, the mean annual run-off of Caliente Creek was estimated to be 35,000 acre-feet. No additional measurements have been made since 1920. Comparison with other streams does not furnish any basis for changing the previous estimate.

Kern River flows north of this area, a ridge of Tertiary material, usually referred to locally as Kern Mesa, occupying the intervening area. The river is from 100 to 200 feet higher than the ground water south of the mesa. Even with this difference in elevation there is nothing in any data available to indicate ground water movement through the mesa. The records on Kern River indicate a gain rather than a loss in its channel above First Point of Measurement. The ground water south of the mesa has very little slope to the south as it would be expected to have if a material supply came from the north. Some movement may occur around the point of the mesa at Bakersfield into the northern part of this area, but such movement is probably small in amount. Well 5-G-17, Fig. 21, in the mesa shows no response to either river or canal conditions.

Wells in this area vary from 100 to 600 feet deep. The wells serving larger areas are usually from 300 to 600 feet deep, deep-well turbine pumps being used.

Water-bearing material of coarse texture resulting in wells of large yield is generally found in the main developed area in township 31 south, range 29 east. Wells in the southern portion of this area need to be deeper in order to secure similar yields. Owing to the coarseness of the material, relatively small drawdown occurs while pumping even with large discharges.

Analyses of water made in 1920 show good quality in the wells in the main pumping area near Arvin. The quality of water from wells along the mesa at the north end of the area varies with the depth of the well. The surface water strata contain sodium sulphate and gypsum. Wells perforated only in the second and third strata show a much smaller amount of these salts.

The general ground water in this area had little slope prior to extensive pumping. There was a total fall of about 5 feet from the east toward the west in 1920. This indicates a relatively free movement of ground water within the area, a condition which is also shown by the material encountered in drilling and the large discharges secured from wells with relatively small drawdown.

Hydrographs of typical wells are shown in Fig. 21. Well 6–H–3 is located at the north of the larger area of pumping. The well was drilled to a depth of 278 feet in 1912, water standing at 212 feet. This has lowered to 216 feet in 1920 and 231 feet in 1925. The lowering in recent years has been steady with little rapid fluctuation due to either draft or recharge.

Well 7–H–1, 320 feet deep, is within the heavily pumped area and illustrates the difficulty in securing records free from the local effect of pumping. A 13-foot lowering from 1920 to 1925 is shown. Well 7–H–9 is a shallow well just beyond the end of the East Side Canal. Little fluctuation except a steady lowering is shown. There is not much pumping near this well.

Well 7–I–1 is near the east side of the area and above the main pumping area. Lowering of nearly 20 feet from 1920 to 1925 is shown. Well 7–I–3 is nearer the pumping area. This well was not observed prior to 1924. Steady lowering is shown.

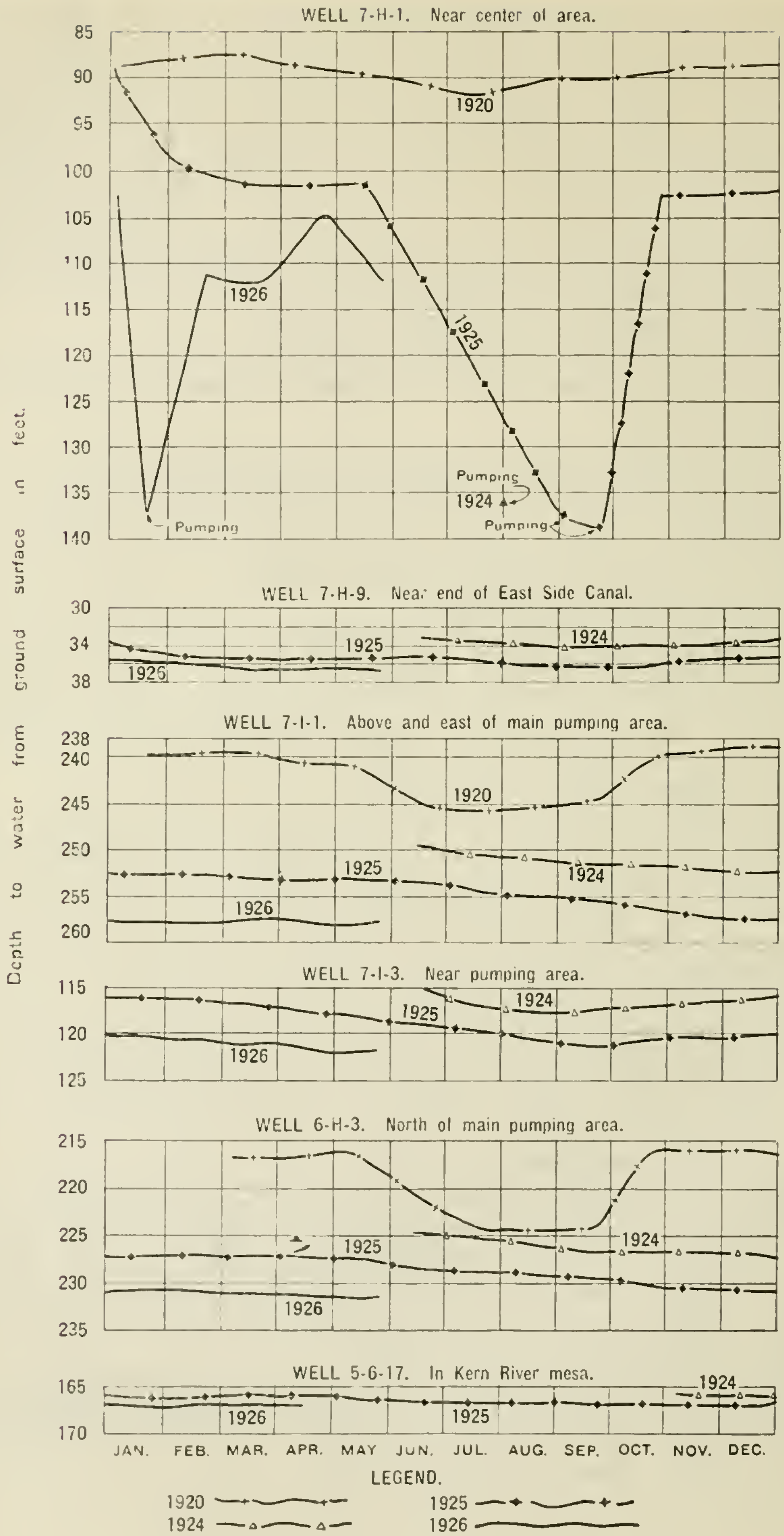


FIG. 21. Hydrographs of typical wells in the area above the East Side Canal.

The 1925 crop census for the area above the East Side Canal gave the following results:

Crop	*Total acres*	*Per cent of total area*
Cotton	6,993	40
Field crops	543	3
Alfalfa	480	3
Orchard	2,950	17
Grapes	5,863	34
Garden	439	2
Melons	44	--
Miscellaneous	125	1
Totals	17,437	100

This includes all area above the canal. Four-fifths of the area irrigated is south of the center line of township 30 south. The gross area above the East Side Canal extending around the edge of the adjacent hill areas to the south line of township 31 south is about 55,000 acres. Present development represents about one-third of this gross area.

The total pumping draft for these lands was not secured in 1925. Data secured in 1920 indicated an average draft of 2.8 acre-feet per acre. Some incomplete data in 1925 indicate that the present gross draft is fully as large per acre as in 1920. The rate of pumping is sufficiently large in many instances to exceed the crop consumption and downward moisture loss will occur. Similar rates of application under canals have always resulted in additions of the ground water usually accompanied by a rise of the water table. As the ground water is relatively deep under most of this area and overlaid by dry materials, the length of time water has been used on some lands may not have been sufficient to result in the downward moisture movement reaching the ground water, but for permanent conditions the actual draft on the ground water will be represented by the net crop use rather than by the gross amounts pumped.

The larger part of the flow of Caliente Creek sinks in its channel before reaching the valley areas. Well 6–I–3 is adjacent to the course of Caliente Creek as it enters this area. Water stands at a depth of about 125 feet in this well. A dug well over 50 feet deep in the creek bottom near Bena has not had water in it in recent years.

In the latter part of April and in May, 1926, unusually heavy local storms occurred in the foothill areas adjacent to Bakersfield. One of these occurred on the lower drainage area of Caliente Creek and resulted in a larger flood run-off of short duration than has occurred in recent years. The well records for this period were examined to determine the effect, if any, of this run-off on the ground water. The wells were read about April 23 and May 23 in 1926. The change during this period in 1926 was compared with the change between similar dates in previous years. For ten wells situated adjacent to and in the direction of movement from Caliente Creek the ground water averaged to hold its elevation in 1926 where in other years an average lowering of 0.4 foot occurred. Some of this difference is due to decreased draft resulting from the decrease in pumping following the rains. The area affected did not exceed 20,000 acres. The total difference would not represent over 2000 acre-feet of water. Well 6–I–3 adjacent to Caliente Creek showed no change during this period. These results illustrate the small amount of actual run-off produced by sudden heavy storms of limited area even though the temporary run-off may be rapid.

Owing to the rapid development that has occurred in this area since 1920, many of the wells observed in 1920 are in use for pumping or not available for direct observation for various reasons so that direct comparisons are not as readily made. However, the ground water contours in 1920 can be compared with those for 1925. This has been done on Map No. 3, which shows the lowering that has occurred in the last five years. Direct observations are available for the lowering in 1925. The lowering averaged about 3 feet over the gross area of 50,000 acres. This is equivalent to a ground water depletion of about 30,000 acre-feet of water. The run-off of Caliente Creek in 1924–25 was not measured, but judged by comparison with other streams, would have been about 40 per cent of normal, or about 14,000 acre-feet. This indicates a total supply used of about 44,000 acre-feet or about 2.5 acre-feet per acre. This appears high and is larger than the probable crop consumption. It is considered to be due to the fact that downward moisture penetration from the newly developed and heavily irrigated areas has not yet reached the ground water.

The comparison of the contours for 1920 and 1925 shows a maximum lowering of about 20 feet for the five-year period. The maximum depletion occurred in the area of heaviest pumping near Arvin. A lowering of 15 feet occurred in the area of larger development in township 31 south. A lowering of between 10 and 15 feet occurred between this area and Edison. Against the edge of the mesa the lowering varied from 15 feet near Edison to 25 feet nearer Bakersfield. These changes have resulted in a reversal of the ground water slope since 1920. Instead of a slight slope from the upper eastern edge of the area to the East Side Canal, a cone of depression now exists under the heavily pumped area in township 31 south with the ground water sloping into this area from all sides.

The run-off during recent years has been below normal and the lowering of the ground water that has occurred may be due to deficiency in supply as well as to the rate of draft. The present acreage with a net crop use of 2 acre-feet per acre would result in a total net draft about equal to the estimated mean annual run-off of Caliente Creek. Some outward movement of ground water into the area under the East Side Canal probably occurs so that unless this can be intercepted by the pumping above the canal, not all of the run-off of Caliente Creek will be available. The estimated mean annual run-off of Caliente Creek is based on incomplete data and may be larger than the actual supply. As the deeper wells under the East Side Canal appear to be only indirectly affected by use under the canal little movement of ground water into the area above the canal is to be expected even with additional lowering and increased ground water slope from the East Side Canal into the area of heavy pumping.

Present development in this area appears to be fully as large as the available water supply can support. An increase in the draft would be expected to result in a continued lowering of the ground water even in years of average run-off. The high lifts now required in this area will reduce the amount of further lowering than can occur without resulting in excessive costs. It is considered that present draft is more liable to be in excess of the supply than the reverse and lowering over a period of average years would probably occur even with the present rate of draft. As only one-third of the gross area is now irrigated, the development of any large part of the remaining area can only be expected to result in a more rapid lowering of the ground water.

GROUND WATER IN EAST SIDE CANAL AREA.

Ground water conditions in the general area southeast of Bakersfield differ above and below the East Side Canal due to the effect of the canal. The East Side Canal area as here discussed consists of the land adjacent to the East Side Canal. It extends about 1 mile to the east above the canal and to the alkali area west of the canal. This area agrees with that used by the Kern River Water Storage District in its analyses and has been adopted in order that their summaries could be used without recomputation. The irrigated lands depend in some cases entirely on canal service and in others entirely on pumping with much land using both sources of supply.

The water supply of this area consists of the delivery to the East Side Canal plus any ground water movement from Caliente Creek or Kern River sources. Ground water derived from Caliente Creek would reach this area, particularly the lower strata, unless intercepted by higher pumping. Little if any movement from Kern River would be expected. A small amount of such movement might occur around the point of the mesa at the north end, the ground water depression in the alkali area between the East Side and Kern Island Canal areas, as shown on Map No. 1, indicates that movement from the west into the East Side Canal area does not occur.

Outward ground water movement from the area probably occurs into the area of high ground water to the west. Loss by evaporation from the area to the west is indicated by the shallow depth to ground water and the alkali character of the land.

Hydrographs of typical wells are shown in Fig. 22. Well 6–H–5 is representative of the deeper wells and shows the lowering during the pumping season and recovery during the winter. Well 6–H–7 is typical of shallow wells affected by flow in the East Side Canal. The ground water in this well is highest in the summer and lowest in the winter, or the reverse of the deeper wells.

The largest lowering of the ground water since 1921 has occurred at the north end of the area. Larger lowerings have also occurred in the area along and above the canal than in the area below the canal as shown on Map No. 3. In some areas below the canal an actual rise has occurred.

The data covering areas irrigated, canal delivery and ground water supply are given in the following table. The areas served by canals are taken from the Canal Company's record for each year: the areas served by pumping were secured in 1919, 1920 and 1925, the remaining years being interpolated. The canal supply is the gross delivery into the East Side Canal. The ground water fluctuations are from October of each year and are available only since 1920. The average ground water fluctuations include the results from both deep and shallow wells.

The service under the East Side Canal is secured under water rights of early priority and does not vary widely with the total flow in Kern River. The supply per acre of canal service only has averaged 4.3 acre-feet per acre per year for the last seven years and fell below 4.0 acre-feet per acre only in 1924, when 2.8 acre-feet per acre were

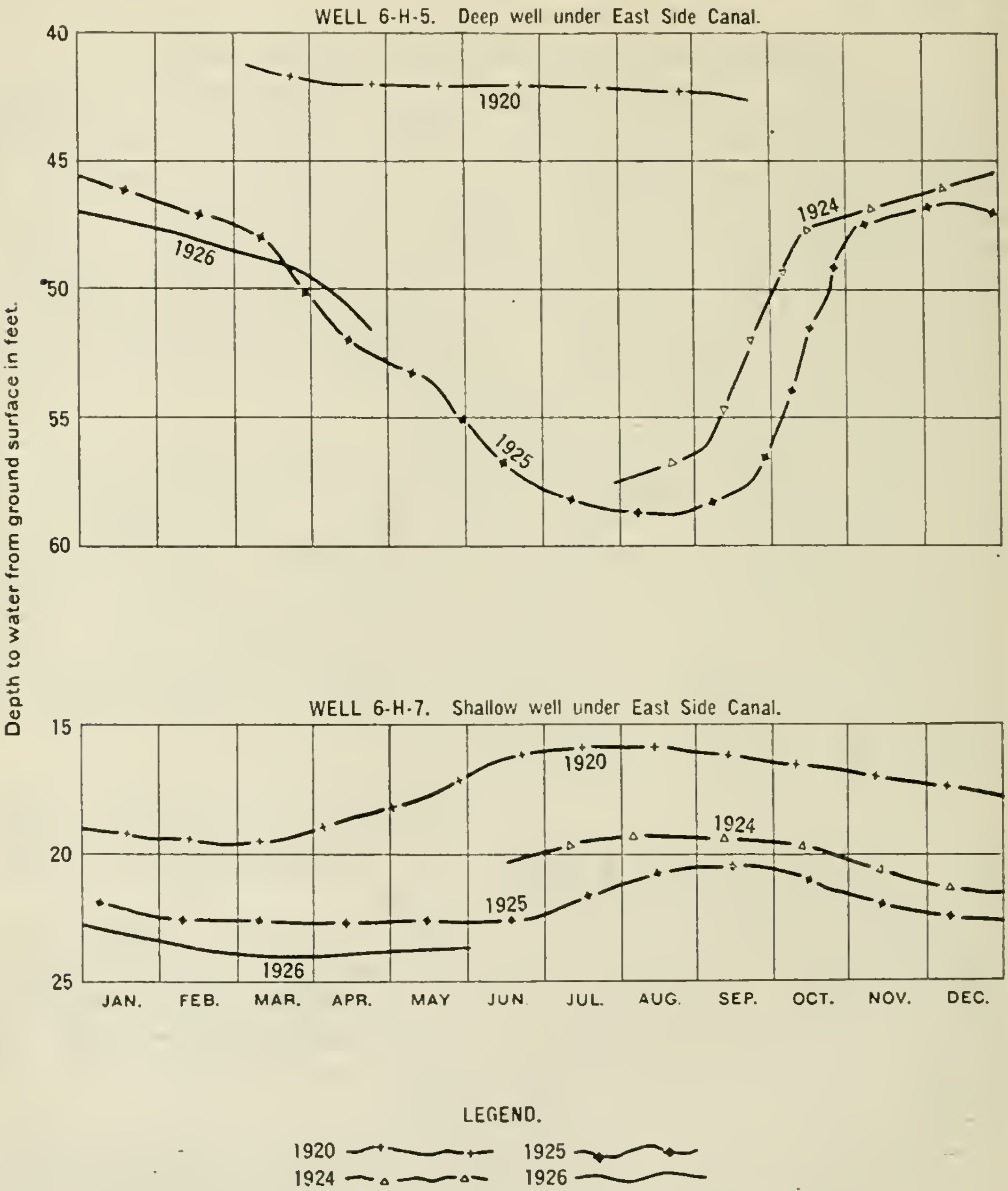


FIG. 22. Hydrographs of typical wells under East Side Canal.

received. These figures include canal losses as well as delivery to the land; conveyance losses have been from 25 to 40 per cent of the total supply.

The area served entirely by pumps under the canal has been increasing, having more than doubled since 1919. In 1919 the pumping area was about one-half that usually served by canals; in 1925 the pump area exceeded the canal area. This relative increase of the pumped area in proportion to the canal served area probably is the main cause for the greater ground water lowering in 1925. A similar rate of increase has occurred in the pumping area adjacent to but above the canal until in 1925 the total pumping area that may be partially

Records of Use of Water and Ground Water Fluctuations Under East Side Canal.

	Area Irrigated—Acres				*Canal water supply*		*Average rise or fall of ground water in feet***
	Under canal						
Year	*From canal*	*By pumps only*	*Outside pumps only*	*Total*	*Acre-feet*	*Acre-feet per acre**	
1919	6,005	2,720	1,615	10,340	25,180	2.43	-----
1920	5,408	3,379	2,760	11,547	25,154	2.18	-----
1921	4,966	4,000	3,260	12,226	24,469	2.02	— .50
1922	5,750	4,630	3,580	13,960	26,583	1.90	— .54
1923	5,821	5,260	3,760	14,840	26,405	1.78	— .57
1924	5,941	5,870	3,930	15,740	16,510	1.05	— .91
1925	5,878	6,600	4,080	16,560	25,726	1.55	—1.15

* Based on total area of canal and pump service.
**Includes both deep and shallow wells.

dependent on the East Side Canal for its ground water supply was nearly twice that served by the canal. The canal supply in 1925 was about the average supply received by this canal. A lowering of over 1 foot occurred, although only one-half of the gross area was cropped. This would indicate that present development in this area exceeds the average water supply.

The water supply received by this area in any year may be used by the crops or soil evaporation or may move outward from the area as ground water flow. Any balance between the elements of supply and use will be reflected in the ground water fluctuations. The variations in the crop area and water supply in different years are not sufficient to enable all of these elements to be separately determined. However, by assuming rates of consumptive use and the drainage factor represented by the ground water fluctuations, the outward ground water movement can be approximated. This has been done in the following table. The consumptive use has been estimated as 2.0 acre-feet per acre and the average drainage factor as 18 per cent.

Year	*Total water supply, acre-feet*	*Estimated crop use, total acre-feet*	*Estimated change in ground water in acre-feet*	*Resulting unaccounted for supply, total acre-feet*
1921	24,700	24,400	—3,000	3,300
1922	26,600	28,000	—3,300	1,900
1923	26,400	29,700	—3,500	200
1924	16,500	31,500	—5,500	—9,500
1925	25,700	33,100	—7,000	— 400

These results indicate that the probable outward ground water movement in excess of any movement into the area is relatively small. The results are fairly consistent except for 1924; the lowering that occurred in this season is not sufficient to account for the crop needs. Some shortage in crop supply probably occurred and some pumping draft may have been supplied from deeper wells not reflected in the ground water fluctuations.

The available data indicate that existing development in this area is larger than present sources of supply can support and that the present conditions of supply and use will result in a progressive lowering of the ground water. This condition may be changed if additional canal supplies are made available to this area. Plans for such supplies are now under consideration by the Kern River Water Storage District.

GROUND WATER IN MAIN CANAL AREA SOUTH OF KERN RIVER.

This comprises a gross area of about 162,000 acres, of which about one-half is included in the Kern River Water Storage District. It includes all lands served by canals on the south side of the river except that served by the East Side Canal. The canals supplying the area have water rights which include the older priorities on the river. In consequence a relatively dependable and adequate service is received on much of the land. This has led to excess use, ground water rise and much less pumping than is found in other areas adjacent to Kern River.

The use practiced in the past has resulted in much land being injured by over-irrigation and high ground water. These conditions with general plans for drainage were discussed in detail in Bulletin 9. No material changes have occurred since 1920, except as the annual conditions are affected by the varying river flow.

The canal diversions into this area for the years 1920 to 1923 averaged about normal. The supply in 1924 was about two-thirds normal and that in 1925 about 15 per cent above normal. The ground water records are incomplete between 1920 and 1924. From 1920 to 1924 there was an average lowering of the ground water of 1.6 feet. The lowering varied from a negligible amount in the eastern portion of the area to 2 to 3 feet in the area adjacent to Kern River. The division of this lowering between the different years is not obtainable from the available records. The canal records indicate that it occurred mainly in 1924, due to shortage in canal supply. In 1925 a general rise averaging 0.4 foot occurred. The rise was larger in the areas more directly supplied by canals.

Hydrographs of typical wells are shown in Fig. 23. Well 6–F–36 is under the Stine Canal. It reflects the canal service quite quickly and shows the rise of the ground water with the increased supply since 1924. Water in this location rose to within 4 feet of the surface in 1920. The lowering due to decreased supply in 1924 was recovered in 1925.

Well 7–F–24 is under the Farmers' Canal and also reflects the canal service. The ground water in 1925 was as high as in 1920. Well 6–F–9 is under the Kern Island Canal. It was higher in the latter part of 1924 and 1925 than in 1920.

Well 8–G–1 is in the bed of Kern Lake. The ground water in the latter part of 1924 and 1925 was lower than in 1920, due to decreased late canal delivery in this area.

Well 7–G–10 is typical of the alkali area southeast of Bakersfield. Little change from year to year is shown, the ground water rising almost to the ground surface. Well 5–G–19 is in Bakersfield. The lowering of 1924 has been recovered in 1925 and 1926.

There is little pumping in this area. In 1925 only nine plants were reported. The wells were from 45 to 140 feet deep and had an average discharge of 1 second-foot. There are a number of artesian wells around Kern Lake, which are used for stock purposes. The yield of these artesian wells is generally insufficient for economical irrigation use. Twelve pumping plants in the area adjacent to the river were operated by the Kern County Land and Water Company in the period following 1900. Four wells were used with each pump and a total discharge per plant of nearly 4 second-feet secured.

In 1920 the area in which the ground water rose within different depths were obtained from the observations on shallow wells distributed over the area with the following results:

Depth to which water rose for at least 30 days in 1920	*Total area, acres*
Less than 2 feet	2,200
2 to 3 feet	7,200
3 to 4 feet	32,800
4 to 5 feet	35,000
5 to 6 feet	34,000
Total	111,200

Similar estimates for 1925 were not prepared but similar results would be shown except for the temporary result of the dry year in 1924. The area in which the ground water rose within 6 feet of the surface represents about two-thirds of the gross area. Of this area, nearly one-half is within the Kern River Water Storage District.

These comparisons indicate that the normal canal diversions into this area will continue to maintain a high ground water. Variations in the depths to water will occur with the variations in canal supply in different years. Present average rates of diversion exceed crop consumption of moisture and drainage is essential on much of this area if adequate crop production is to be secured. The physical conditions for pumping are favorable on much of the area near the river. Such pumping in addition to furnishing relief as drainage would also make available additional water supply.

GROUND WATER IN AREAS NORTH OF KERN RIVER.

Lands served by canals diverting on the north side of Kern River can be divided into two classes. Lands adjacent to the river have received a more dependable service. Canals extending to the north have received flood water service with wider variations in the amount received in different years. Such areas are also removed from the direct effect of flow in Kern River itself. Pumping has been extensively developed in this area along its western and northern portions, the canal service being limited mainly to the remaining area. In Bulletin 9, this northern area was referred to as the Shafter, Wasco and MacFarland area; the same name is used in this report. The areas nearer the river are described under the general title of the Rosedale and the Pioneer areas.

GROUND WATER IN ROSEDALE AREA.

This term is used to describe the area lying north of Kern River and south of the Seventh Standard Parallel south and extending from the Beardsley Canal on the east to the Goose Lake Slough and Pioneer Canal areas on the west. It has received relatively large amounts of canal service, pumping being used as a supplemental supply as well as entirely for some areas. Ground water records have been maintained for some wells in this area continuously since 1919.

Wells in the Rosedale area are usually shallow, varying from 60

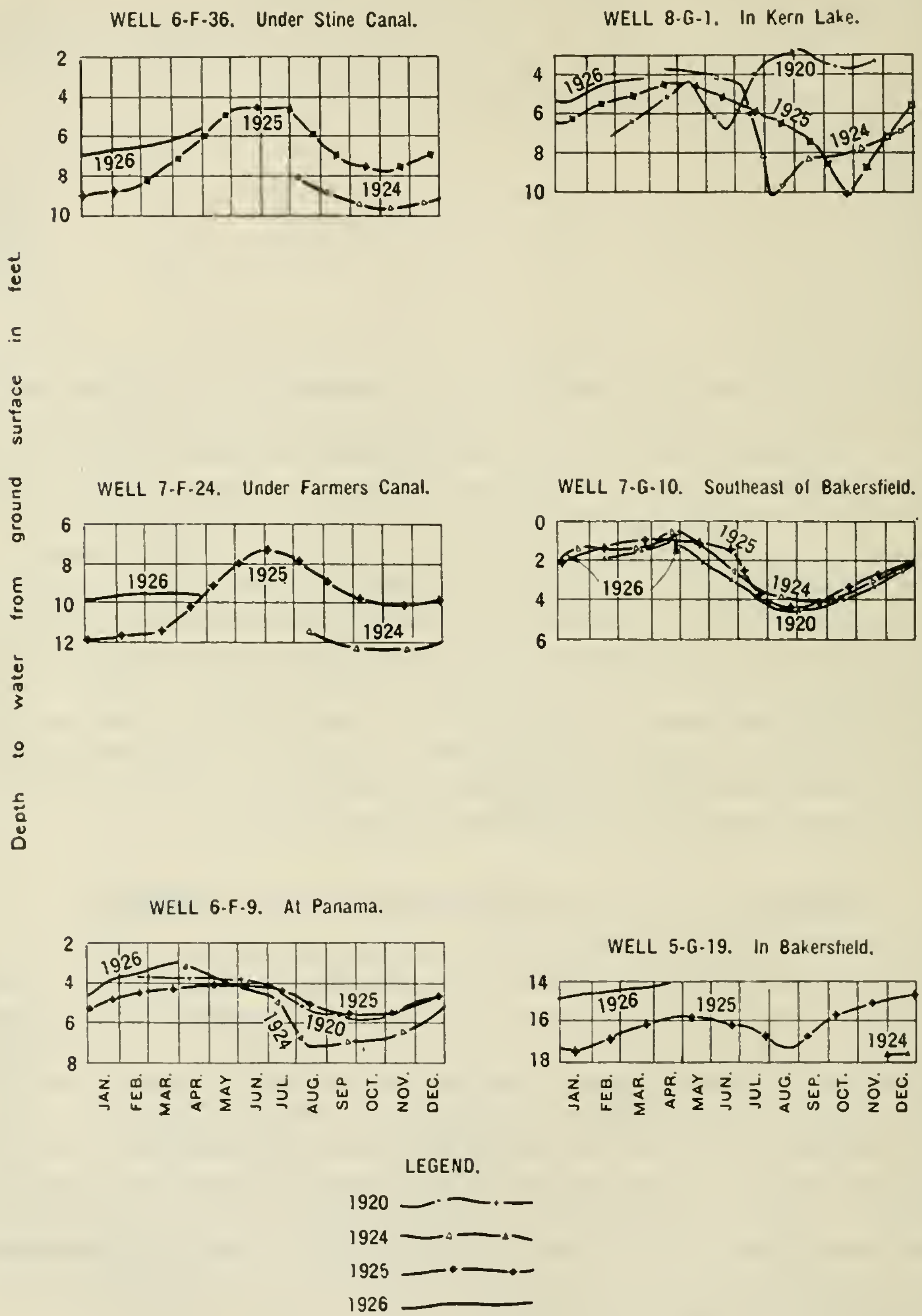


FIG. 23. Hydrographs of typical shallow wells in main area south of Kern River.

to 100 feet in depth. Discharges as large as 3 second-feet are secured. Near Rio Bravo, the wells average somewhat deeper with discharges of from 1 to 3 second-feet. The depth to ground water is relatively small as shown on Map No. 2.

Hydrographs of typical wells are shown in Fig. 24. Well 5–F–24 is near the river at the head of the Calloway Canal. Quick response

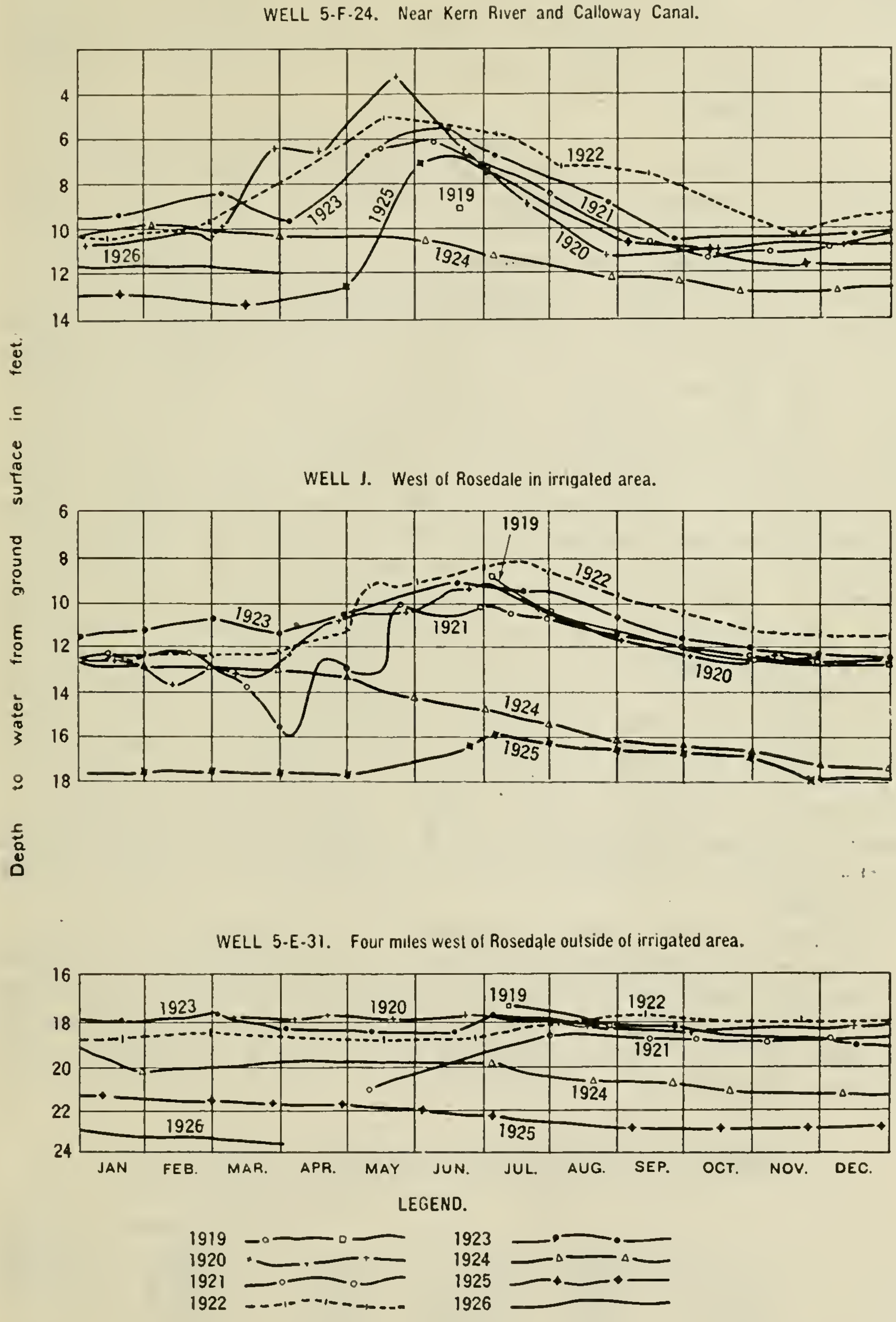


FIG. 24. Hydrographs of typical wells in the Rosedale Area.

to flow in the river and canal is shown. Nearly all of the lowering in 1924 was recovered in 1925. The fluctuations reflect the extent of the stream flow with no indication of any continued lowering.

Well J is west of Rosedale within the irrigated area. A ready response to canal service is shown. The lowering in 1924 was not recovered in 1925. In the earlier years little tendency toward lowering is shown. The shortage in supply in 1924 resulted in a lowering of about 5 feet; in 1925 the supply nearly maintained the ground water, the lowering being less than 1 foot. From 1920 to 1924 little lowering occurred.

Well 5–E–31 is located 4 miles west of Rosedale and outside the area canal irrigated. A continual lowering is shown which has a tendency to increase in amount in recent years due to the smaller canal supply on lands to the east

The water supply in the Rosedale area is derived from canal diversions and river seepage. The ground water in the oil fields to the east has been lowered so that a cone of depression exists and ground water movement from the east, even if it occurred under natural conditions, would now be intercepted. Kern River loses some water in the portion of its channel adjacent to the Rosedale area. It is doubtful if much of such seepage moves into the Rosedale area as ground water at Rosedale prior to the construction of the canals is reported to have been about 50 feet lower than at present. River seepage under natural conditions was not sufficient to raise the ground water at Rosedale to its present elevation, although the ground water slope under the early conditions would have been relatively steep in this direction. While some river seepage into this area may occur its amount is considered to be relatively small. Present ground water conditions are the result of irrigation and are dependent on irrigation for their maintenance.

The supply received from irrigation in this area is relatively large and pumping has been less extensively developed than in the areas to the north. The crops irrigated consist of about one-half alfalfa and one-half trees, vines and annual crops. The normal ground water in parts of the area is sufficiently near the surface to have caused damage to the land and to result in some loss of moisture in excess of normal crop needs.

The records of the areas irrigated, the canal supply received into the area and the resulting fluctuation in the ground water are shown in the following table for each season since 1919. In general the ground water fluctuation varies with the extent of the canal supply per acre of crop. Some variations from a direct relationship occur however, particularly in 1923.

Irrigation and Ground Water Fluctuations in Rosedale Area.
Gross Area 43,840 Acres.

	Area irrigated, acres			*Canal water*		
Year	*From canals*	*Pumps only*	*Total*	*Total acre-feet*	*Acre-feet per acre of total crop area*	*Average rise or fall in water table, feet*
1919 ______	11,225	3,420	14,645	56,784	3.87	
1920 ______	15,253	2,607	17,860	77,853	4.26	— .30
1921 ______	11,600	3,200	14,800	56,488	3.81	— .13
1922 ______	15,556	2,600	18,156	98,737	5.43	+1.56
1923 ______	12,653	3,000	15,653	68,789	4.39	—0.94
1924 ______	0	6,080	6,080	0	0	—4.79
1925 ______	7,831	4,000	11,831	35,842	3.03	—1.28

In Fig. 25 the records are plotted for the area as a whole and separately for the area in each of the three townships included. The area in township 29 south, range 25 east, consists of the part of the east half of this township north of Goose Lake Slough. All of township 29 south, range 26 east, is included except the south row of sections. All of township 29 south, range 27 east, north of the river and east of the Lerdo Canal is included.

In township 29 south, range 25 east, there is no canal irrigation and little pumping. The results for the different years are less consistent than for the other areas. To some extent there appears to be a secondary effect from the preceding year, the rise in 1923 following the larger supply of 1922, being greater than would have been expected from the supply in 1923 and the lowering in 1925, following the dry year in 1924, being greater than would have been expected from the supply in 1925.

For the two eastern townships, the lowering in 1923 was larger than would have been expected from the results in other years. This is probably, at least partly, due to the higher ground water resulting from the larger diversion in 1922 with a resulting increase in outward ground water movement and local soil evaporation. The ground water at the end of the 1922 season was about $1\frac{1}{2}$ feet higher than in 1920. The larger losses resulting from this condition probably account for the difference in results in 1923.

The water supply received in the Rosedale area may be consumed either by crop use or soil evaporation, or may pass outward from the area as ground water movement. The results given in preceding table supply data only on the area of crops and do not give any direct measure of these different items, although their sum is indicated by the amount of the supply received and the resulting ground water fluctuations. If these different items of disposal of the water supply were constant the years covered by the observations would permit a solution for their individual amount. However, the elements are not constant and the rate of variation with other factors is not known. Crop use of moisture may be at least closely proportional to the area cropped in different years, but soil evaporation and outward movement of ground water vary with the height of the ground water. These elements can only be estimated by assuming values for the crop use and drainage factor and considering that the remaining unaccounted for supply represents the sum of outward ground water movement and excess soil evaporation. This has been done in the following table.

A crop use of 2.0 acre-feet per acre has been assumed based on general comparison with other areas. This represents the crop use expected under the local conditions for land free from the effects of high ground water, any additional crop due to high ground being considered as a part of the excess soil evaporation loss.

A drainage factor of 18 per cent has been used. This is based on results in other areas. It is a relatively high value which is considered warranted by the conditions in this area where the lowering is within the surface material which averages fairly coarse in texture.

The results of these assumptions are as follows:

Year	Total water supply acre-feet	Estimated crop use at 2.0 acre-feet per acre, total acre-feet	Estimated change in ground water within area, total acre-feet	Resulting unaccounted for supply, acre-feet	Total ground water change since 1920, feet
1920	78,000	36,000	— 2,000	44,000	.0
1921	56,000	30,000	— 1,000	27,000	—0.1
1922	99,000	36,000	+12,000	51,000	+1.4
1923	69,000	31,000	— 7,000	45,000	+0.5
1924	0	12,000	—38,000	26,000	—1.3
1925	36,000	24,000	—10,000	22,000	—5.6

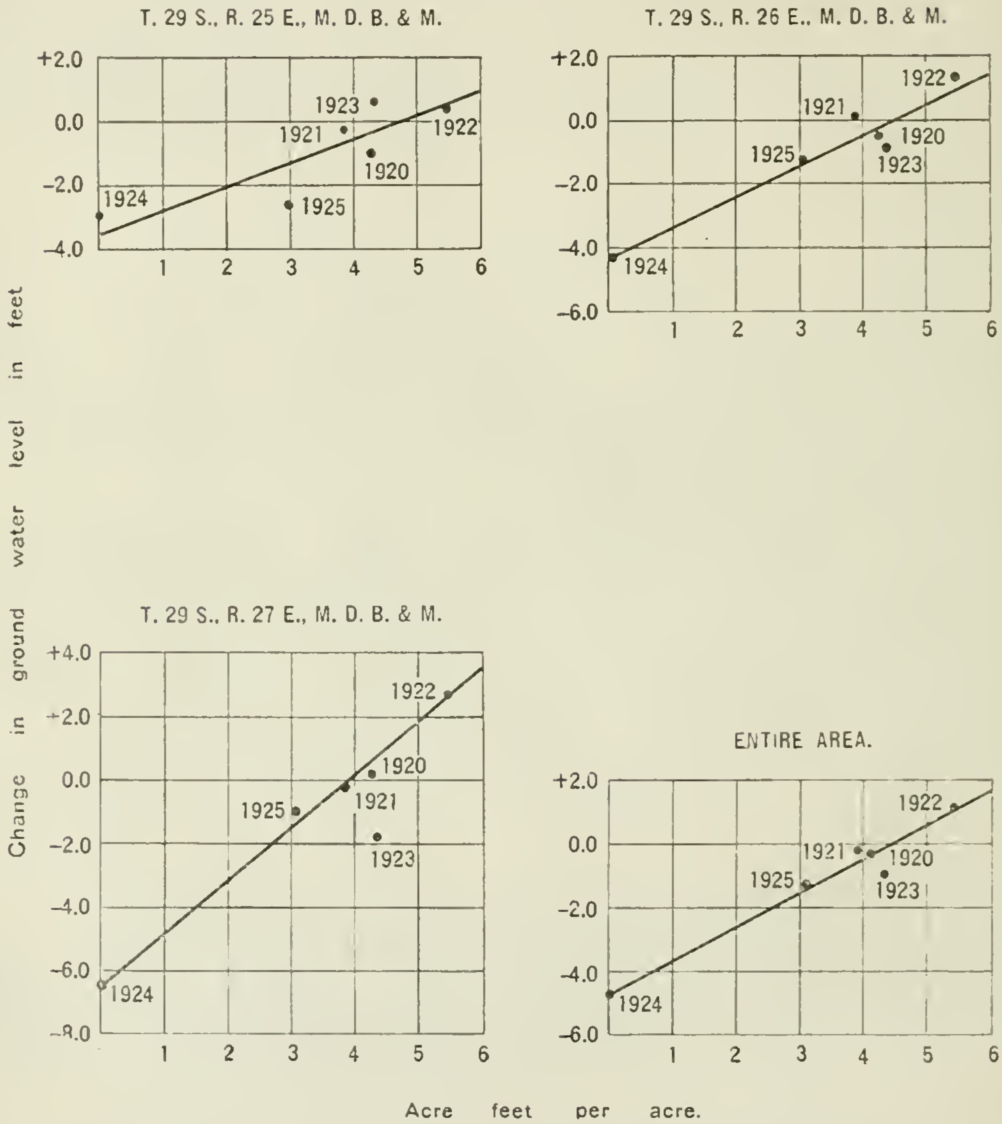


FIG. 25. Relation of water applied in irrigation, from both canals and wells, to change in level of ground water in Rosedale Area.

Variations in the estimate of consumptive use or drainage factor will affect the resulting estimate of unaccounted for supply. Material changes would be required to change the general nature of the results, however.

The resulting unaccounted for supply appears to vary widely. These variations are, however, at least partly, accounted for by the changed conditions in 1924 and 1925, leaving 1921 as the only inconsistent result. A greater lowering of the ground water in 1921 would have been expected than the lowering that occurred.

The results for 1920 to 1923, inclusive, represent a period of larger canal supply, higher ground water and consequently larger ground water losses. An unaccounted for supply of about 45,000 acre-feet per year appears to be indicated by these results.

The lack of any canal supply in 1924 resulted in all crop use being supplied from the ground water. This, with outward ground water movement, resulted in a material lowering. Such lowering resulted in the ground water being below the influence of surface evaporation and probably also reduced the outward movement. The smaller unaccounted for supply may be a measure of the conditions that will occur with such lower ground water.

In 1925 the supply was still deficient and the ground water remained lower than in former years. The unaccounted for supply was less in 1925 than in 1924.

The average canal supply received by this area is about 85,000 acre-feet per year. The average area irrigated by canals and pumps may be 20,000 acres. With stable ground water this would result in a surplus supply over crop needs of about 45,000 acre-feet. Present average conditions in this area would be expected to replace the ground water lowering of 1924 and 1925 and restore the previous rate of outflow and excess soil evaporation loss. The present average supply for this area exceeds the present crop demands and an increase in pumping should be feasible without material permanent ground water lowering below the depth sufficient to prevent soil evaporation and reduce outward ground water movement. The lowering of the ground water in 1924 and 1925 resulted in a reduction of about 20,000 acre-feet per year in the indicated losses from the area. Further lowering of the ground water should still further reduce outward movement. The extent of such reduction with any given amount of lowering can not be predicted, but a lowering within the limits of economical pumping should result in a further reduction in outflow. While the changed conditions resulting from the absence of canal supply in 1924 have not been in effect sufficiently long to enable dependence to be placed on the numerical results indicated, the records presented appear to justify the conclusion that a material reduction in the present delivery to this area could be made without resulting in a shortage in supply, provided the ground water is maintained below the high levels found from 1920 to 1923.

GROUND WATER IN SHAFTER, WASCO AND McFARLAND AREA.

This area extends from the 7th Standard Parallel south to between McFarland and Delano on the north and from the Lerdo Canal westward to include the main pumping areas west of Shafter and Wasco. This area depends mainly on the Lerdo and Calloway canals and on Poso Creek for its ground water replenishment. The western boundary of the area dependent on these sources of supply is not definite. In the lower valley areas to the west, artesian wells have been obtained; wells formerly flowing continuously now flow, if at all, only during the winter months, however. On the south, the line of division between the area affected by recharge from the Rosedale area and the area affected only by use under the Calloway canal is similarly indefinite.

The areas irrigated in this area, both by canals and by pumping, have been canvassed at different times. The ground water fluctuations have also been determined for each season, the seasons ending September 15. This date was selected as the lowest point of the ground water cycle, a rise usually occurring after this date. These results, including the canal deliveries, are taken from the data compiled by the Kern River Water Storage District.

The canal service in the area south of the 7th Standard Parallel south has been more dependable than that in the area north of the parallel. More complete canal service has been received south of the parallel and pumping is less extensive. The ground water slopes, fluctuations of wells and other records indicate that the ground water south of the parallel has only a limited effect on the supply north of the parallel and the ground water in the area north of the parallel is considered to be mainly dependent on the surface water supply entering the area.

The sources of surface supply are the Lerdo and lower Calloway canals and Poso Creek.

The records of canal supply are given in the following table. The quantities are those measured at what is known as Second Point Calloway, where the Calloway Canal enters this area and at the diversion of the Lerdo Canal from the Beardsley Canal. Some delivery from Calloway Canal above Second Point, which is used in this area, is also included:

	Total acre feet						30-year
Canal	*1920*	*1921*	*1922*	*1923*	*1924*	*1925*	*mean*
Calloway Canal, above second point	3,100	14,300	19,400	5,400	0	3,300	10,000
Second point	45,000	29,600	78,300	26,400	0	10,400	66,000
Lerdo Canal	8,050	11,100	19,600	12,600	0	4,100	18,200
Totals	56,150	55,000	117,300	44,400	0	17,800	94,200

The flow of Poso Creek above its entrance into this area has been measured since 1919 with the following results:

Year	*Total run-off acre-feet*
1920	9,270
1921	4,510
1922	7,770
1923	10,050
1924	0
1925	7,360

The probable mean annual run-off of Poso Creek has been estimated as 20,000 acre-feet, the years covered by the records were all below normal in precipitation.

Early records of ground water in this area are fragmentary. Two wells were drilled in 1876 to obtain stock water for use in the construction of the Calloway Canal. One well was located in section 27, township 28 south, range 26 east, water standing 94 feet from the surface. In 1920 ground water at this location stood 58 feet higher than this elevation. The other well was located in section 2, township 28 south, range 25 east, water standing 105 feet from the surface. In 1920 ground water at this location stood 51 feet higher than this elevation. A third well, near Rosedale, was 59 feet higher in 1920 than in 1876. These records indicate that the present ground water in this general area is the result of losses from irrigation rather than from natural sources.

The lower hill areas to the east represent tertiary formations. These dip beneath the surface fill and may extend entirely under the area. Such tertiary formations are, however, at considerable depth and all pumping now practiced is from the more recent valley fills. Wells in the tertiary formation due to its finer texture would give smaller yields than those in the recent alluvium. Conditions of replenishment are also unfavorable in the tertiary material, as its outcrop is above the canals and in an area of limited precipitation and consequent small absorption into ground water strata.

The following discussion regarding ground water in this area has been based on the conclusion that the only sources of supply of appreciable amount are those received from canal diversions and Poso Creek.

The data on the areas irrigated, the water supply and the ground water fluctuations for each year since 1919 are summarized in the following table. The area irrigated by wells has increased steadily. The water supply per acre of total irrigated area has varied widely in the different years. Such variations are reflected in the resulting ground water fluctuations. Very little of the pump served area receives any canal service.

The ground water fluctuations in this area reflect the composite result of several factors. These include the extent of the ground water supply received, the amount of use by canal served lands, the amount of pumping, and outward ground water movement. The balance between elements of supply and use is secured from or added to the accumulated ground water. The amount of the ground water fluctuation depends on the extent of this balance and the amount of ground material that is drained or filled in order to supply or store the balance.

Summary of Areas Irrigated, Water Supply and Ground Water Fluctuations in Shafter-Wasco-McFarland Area.

	Gross area, 181,000 acres							
	Area irrigated, acres			*Water supply, acre-feet*				
Year	*From canals*	*By wells*	*Total*	*From canals*	*Poso creek*	*Total*	*Water supply, acre-feet per acre of total irrigated area*	*Average lowering of ground water feet*
1919	18,970	31,000	49,970	56,308				
1920	14,130	30,890	44,930	56,154	9,270	65,424	1.45	—1.8
1921	4,291	33,600	37,890	55,034	4,510	59,544	1.58	—2.12
1922	17,202	36,500	53,700	117,324	7,770	124,094	2.32	—0.18
1923	9,737	39,200	48,940	44,360	10,050	54,410	1.11	—3.10
1924	0	41,994	41,994	0	0	0	0	—4.60
1925	4,574	44,800	49,370	17,802	7,360	25,132	.52	—5.24

NOTES.—Areas irrigated by wells determined in 1919, 1920, and 1924 and interpolated for other years.

Lowering of ground water in 1920 based on records for less than the full year.

The area served by canals varies with the water supply. Irrigation from canals is now practiced under conditions which result in heavy rates of application on the lands served with consequent large additions to the ground water. Such losses would be reduced with improvements in present canal irrigation practice. Of the gross area of 181,000 acres included in the area here considered, only about one-eighth is normally irrigated from canals. In recent years the actual area so irrigated has been less than this amount due to deficiencies in stream flow. The area now served by pumps is about one-fourth of the gross area.

Outward ground water movement from this area may occur. Ground water is obtainable in areas to the west and north toward which the ground water slopes; usually in wells of greater depth than those required within the area itself. The amount of any such outward movement would depend mainly on the slope of the ground water and the extent and character of the materials through which movement occurred. Such outflow would be relatively constant in different years and largely independent of the variations in annual supply. It would be affected by increased pumping within the area to such extent as such pumping may intercept such outward movement or the lowering resulting from pumping may reduce the slope or the area through which movement occurs.

Prior to canal construction within the area the only material source of supply was Poso Creek. As previously stated the ground water was over 50 feet lower in 1876 than in 1920. Apparently all ground water received from Poso Creek passed through this area without requiring a water table above that found in 1876. This would indicate an outward ground water movement of 15,000 to 20,000 acre-feet per year under such conditions. The rise in ground water since canal construction would be expected to result in an increase in such outflow.

From 1876 to the beginning of pumping about 1910 there appears to have been an average rise of the ground water of about 1½ feet per year. The probable average annual supply reaching the ground water in this period was about 60,000 acre-feet. The outflow would increase as the ground water rose and would have been a maximum just prior to the beginning of pumping. The ground water lowering of about 20 feet since pumping began and the interception of outflow by pumping have probably reduced the outflow materially below that which occurred prior to pumping.

There are five years of record for which data are available on the area of crops, the water supply and the ground water fluctuations. The unknown elements in the ground water balance for each year are the actual use of moisture by crops, the outward movement of ground water and the moisture made available by draining an acre-foot of soil volume. The number of years covered by the records enables the amount of these three unknowns to be estimated. These years include two of small supply, two of less than normal supply, and one of about normal. The moisture made available by draining a given soil volume, sometimes referred to as the drainage factor, is usually expressed as a percentage of the soil volume drained.

For any year the water supply must equal the crop use plus the outflow plus or minus the water represented by the ground water fluctuations. If the crop use and outflow exceed the supply received, lowering of the ground water will occur to supply the deficiency and the water represented by such lowering is the equivalent of additional water supply. If the supply exceeds crop use and outflow the ground water will rise by an amount represented by the excess supply.

These principles were applied to the data in the preceding table and a solution for the three unknown factors attempted. The values of these factors which seem to more nearly fit these results were a drainage factor of about 12.5 per cent, a consumptive use of from

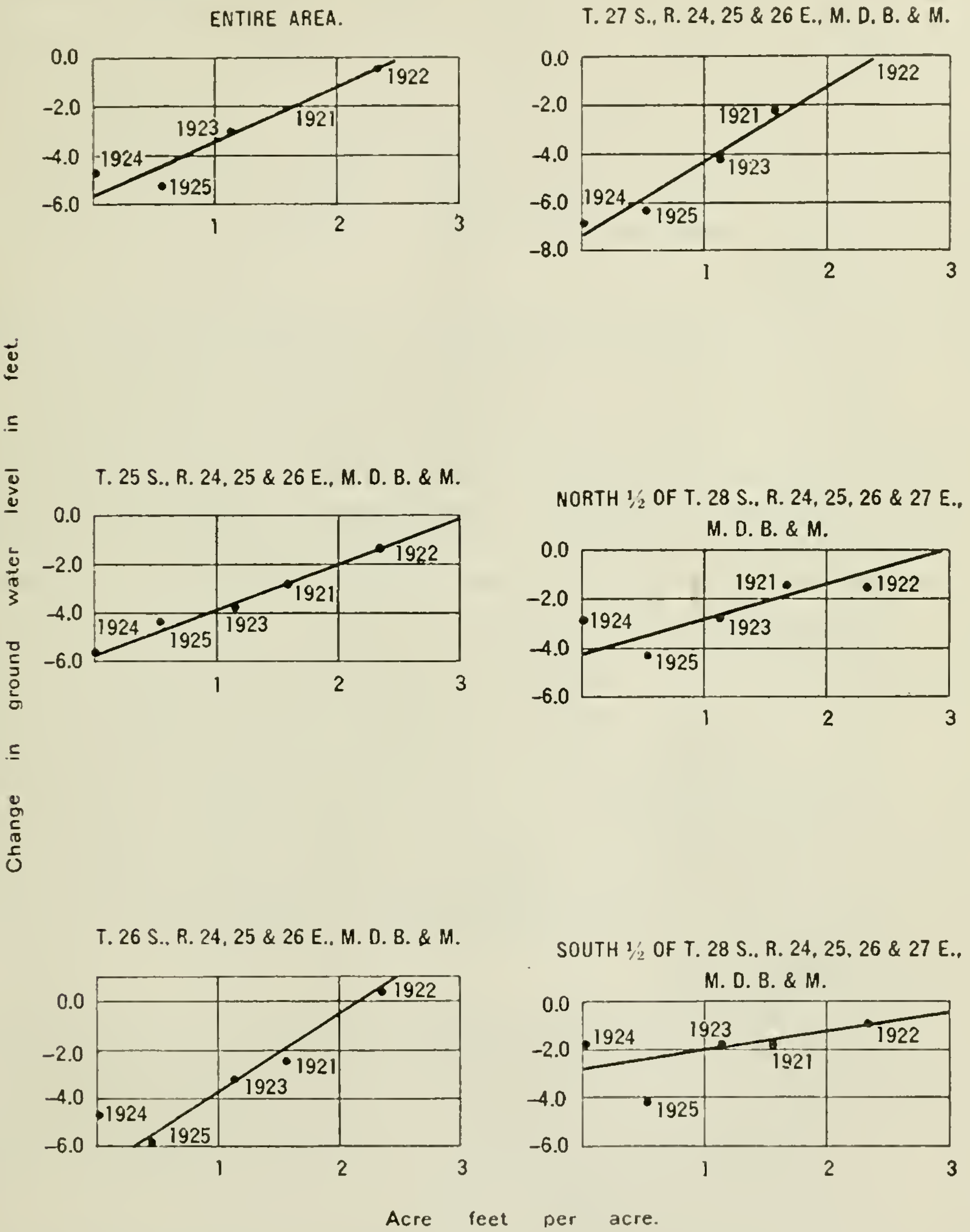


FIG. 26. Relation of water applied in irrigation, from both canals and wells, to change in level of ground water in Shafter, Wasco, and McFarland Areas.

1.8 to 2.1 acre-feet per acre of crop and an outflow of about 25,000 acre-feet per year.

The drainage factor is in fair agreement with what would be expected in an area of this character. Drainage of water-bearing material may represent 25 to 35 per cent of the volume drained. However, as the ground water lowering includes strata that are impervious and do not yield water, the average drainage factor of any large area is always less than that expected from saturated material.

The consumptive use indicated represents the water actually used by plant transpiration or soil evaporation. It is less than the amounts pumped as losses by seepage back into the ground occur. Records of pumping plant operation indicate a gross pumping draft of about 4 acre-feet per acre. Much of this returns to the ground water as seepage from reservoirs or ditches and percolation losses from lands heavily irrigated. That such downward movement occurs on heavily irrigated lands in this area is shown by well records near lands canal irrigated which may rise 10 to 15 feet following heavy flooding.

The indicated consumptive use is somewhat higher than might at first be expected, based on comparison with other areas. However frequent irrigations are practiced and much of the land double cropped or intercropped.

The outward ground water movement represents the net movement. If movement into the area occurs, such as from the Rosedale area, the gross outward movement would equal the figures given plus the amount of any additional inflow not considered in the comparisons as made.

In Fig. 26 the ground water fluctuations have been plotted against the water supply received for the different years. The indicated relationship is, in general, consistent. The results for 1920 are incomplete, as the ground water records do not cover the full year. The area cropped varies from 21 to 30 per cent of the gross area in the different years. The amount of the fluctuations required to supply a deficiency in supply will vary with the per cent of the gross area being irrigated. When corrections for the varying percentage of the gross area irrigated in each year are applied the points for the different years fall more closely in line than shown in Fig 26. The results for 1924 and 1925 are not in close agreement. The lowering in 1924 was less than would have been expected by comparison with 1925. In 1924 the lowering of the ground water resulted in many pumping plants being unable to secure their former discharge and reduced pumping resulted. These conditions were largely adjusted by the lowering of pumps prior to the 1925 season.

In Fig. 26 similar curves for the different parts of the area are also shown. As the horizontal scale represents the average supply for the whole area, the results would not be expected to be consistent with the local ground water fluctuations as the areas and amounts of both canal and pump service vary in the different parts of the area. Certain general conditions are shown however. The data on which Fig. 26 is based are shown in the following table.

Less lowering has occurred in township 28 south than in other parts of the area. This includes the area of pumping near Shafter. There is a smaller percentage of the gross area irrigated by pumps in the south half of township 28 south which probably largely accounts for its smaller lowering although the canal irrigation and possibly ground water movement from the Rosedale area may also be factors.

Ground Water Fluctuations in Different Parts of Shafter-Wasco-McFarland Area.

Area	*Gross area Acres*	*Mean change in ground water elevation in feet* 1920–21	1921–22	1922–23	1923–24	1924–25	1920–25
T. 25 S., Rs. 24, 25, 26, E.	23,040	—2.88	—1.35	—3.76	—5.77	—4.40	—18.16
T. 26 S., Rs. 24, 25, 26 E.	46,080	—2.50	+0.49	—3.06	—4.68	—5.95	—15.70
T. 27 S., Rs. 24, 25, 26 E.	50,560	—2.12	—0.13	—4.03	—6.77	—6.38	—19.43
N. ½ of T. 28 S., Rs. 24, 25, 26, 27 E.	30,930	—1.41	—1.50	—2.62	—2.97	—4.21	—12.71
S. ½ of T. 28 S., Rs. 24, 25, 26, 27 E.	30,720	—1.65	—0.84	—1.67	—1.66	—4.02	—9.81
Totals	181,330	—2.12	—0.48	—3.10	—4.60	—5.24	—15.54
Water supply acre-feet per acre of crop area		1.58	2.32	1.11	0	0.52	

Township 27 south represents the heavily pumped Wasco area and shows the maximum lowering. The average lowering in township 27 south, range 24 east, which includes the main pumping area was 19.5 feet for this period. The lowering to the east in township 27 south, range 25 east, was 25.5 feet. Township 27 south, range 25 east, includes the areas served by canals and reflects the extent of such service. Ground water rose 2.5 feet in 1922 with large canal supplies but fell 9.9 feet in 1924 with no canal supply.

Township 26 south reflects the effect of canal use in 1922, being the only area that rose in that year. It also receives some benefit from Poso Creek. Township 25 south is further removed from canal irrigation and Poso Creek and shows larger lowering.

The preceding discussion furnishes a basis on which to estimate the relation of present use in this area to the average water supply. As the supply received in the last five years has been only 43 per cent of the average the lowering that has occurred does not of itself indicate an overdraft on the ground water.

The average canal supply has been 94,200 acre-feet per year. The average run-off of Poso Creek has been estimated as 20,000 acre-feet, giving a total average supply of 114,200 acre-feet. The present pumped area is 50,000 acres. In normal years about 18,000 acres are irrigated from canals; the average may be 12,000 acres. If the crop use is 2.0 acre-feet per acre, 124,000 acre-feet would be required for the average crop area. An outflow of 25,000 acre-feet gives a total average demand of 149,000 acre-feet, or 34,800 acre-feet in excess of the average supply. With present development and average water supply conditions a lowering of about 1.5 feet per year would be expected. The only year covered by the observations in which an average water supply was received was 1922. With 8300 acres less of pumping area a lowering of ½ foot occurred which is in agreement with the above estimate.

Wells in this area are generally less than 200 feet in depth. A few wells of about 500-feet depth are in use and the tendency is toward the use of deeper wells. Larger discharges are usually secured from the deeper wells.

There has been some discussion as to whether the deeper wells secure a different source of supply than the shallow wells and whether similar fluctuations would be shown. The Hoover farm drilled deeper wells in 1921 and records of their fluctuation can be compared with those

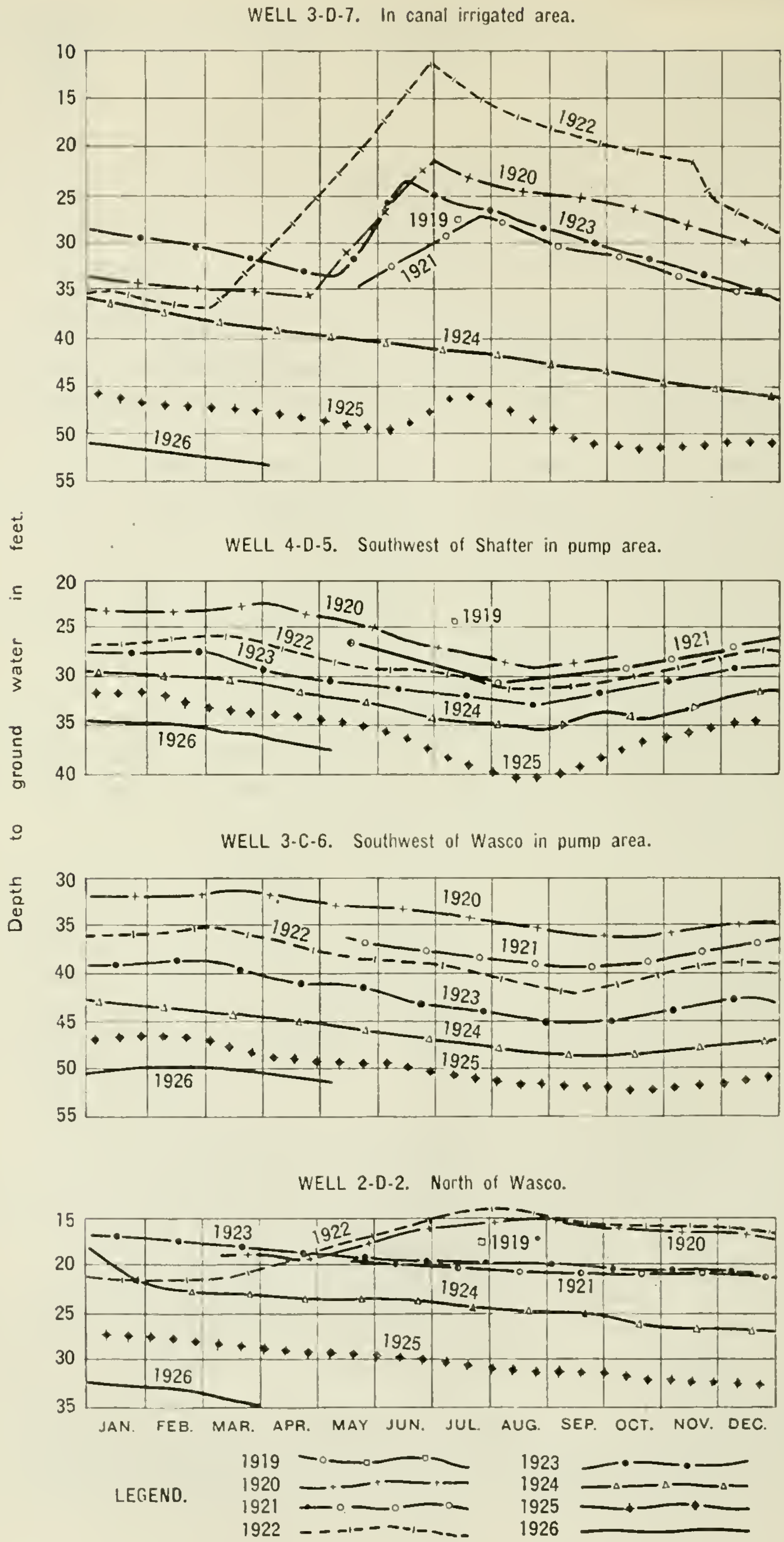


FIG. 27. Hydrographs of typical wells in Shafter and Wasco Areas.

of shallow wells on adjacent areas. These wells are in sections 29 and 30, township 27 south, range 25 east, between Wasco and Shafter, and at the eastern edge of the heavily pumped area. The depths vary from 405 to 562 feet.

Readings on these wells for the date of drilling and also for the spring of 1926 have been furnished by Mr. Harvey Kilburn, superintendent of the Hoover farm. The results are as follows:

Well	*Year installed*	*Years since drilled*	*Total lowering since drilling*
29–A	1921	5	21.5
29–B	1921	5	25
29–C	1921	5	23
29–D	1921	5	28
29–E	1925	1	1
30–A	1921	5	19
30–D	1925	1	2
Sec. 31–1	1922	4	19
31–2	1923	3	19

The average lowering on the five wells drilled in 1921 was 23.3 feet for the five-year period.

In order to compare these results with those of shallow wells, the records of 8 adjacent wells observed by the Kern River Water Storage District were examined. The lowering for the same period averaged 18 feet. The average lowering in township 27 south, range 25 east, from September, 1920, to September, 1925, was 25.5 feet. These results indicate that these deeper wells have shown similar effects to those shown by the shallow wells.

The logs of the deeper wells show strata of considerable thickness of clay. Percolation of water through such strata would occur, if at all relatively slowly. However comparisons of the logs of these wells show no similar or connected clay strata occurring in the different wells. Such clay strata if not continuous would not prevent commingling of the water in the upper and lower strata and it is considered that such commingling occurs.

If the water secured from the deeper strata is not supplied from the canal delivery and Poso Creek run-off, it would have only a limited replenishment. Other sources of supply would be the absorption in foothill areas to the east, which would be very limited in amount due to the small precipitation received. Deep wells have the advantage of greater percolating area and give more discharge with less drawdown, but it is not considered that they secure any different source of supply than that obtained from the shallow wells. They may have the further advantage that by drawing from deeper strata more of the outward ground water movement may be intercepted for use within the area.

The character of the ground water fluctuations is illustrated by the hydrographs of typical wells in Fig. 27. Well 3–D–7 is within the area receiving canal service. The ground water responds rapidly to adjacent irrigation, the rise varying from 25 feet in 1922 with heavy irrigation to zero in 1924 with no irrigation. No winter rise due to rainfall or run-off in Poso Creek is shown. Except for the effect of canal irrigation, the ground water in this well shows a relatively steady lowering at the rate of about 10 inches per month. Such lowering would be due to outward ground water movement toward the pumping area near Wasco.

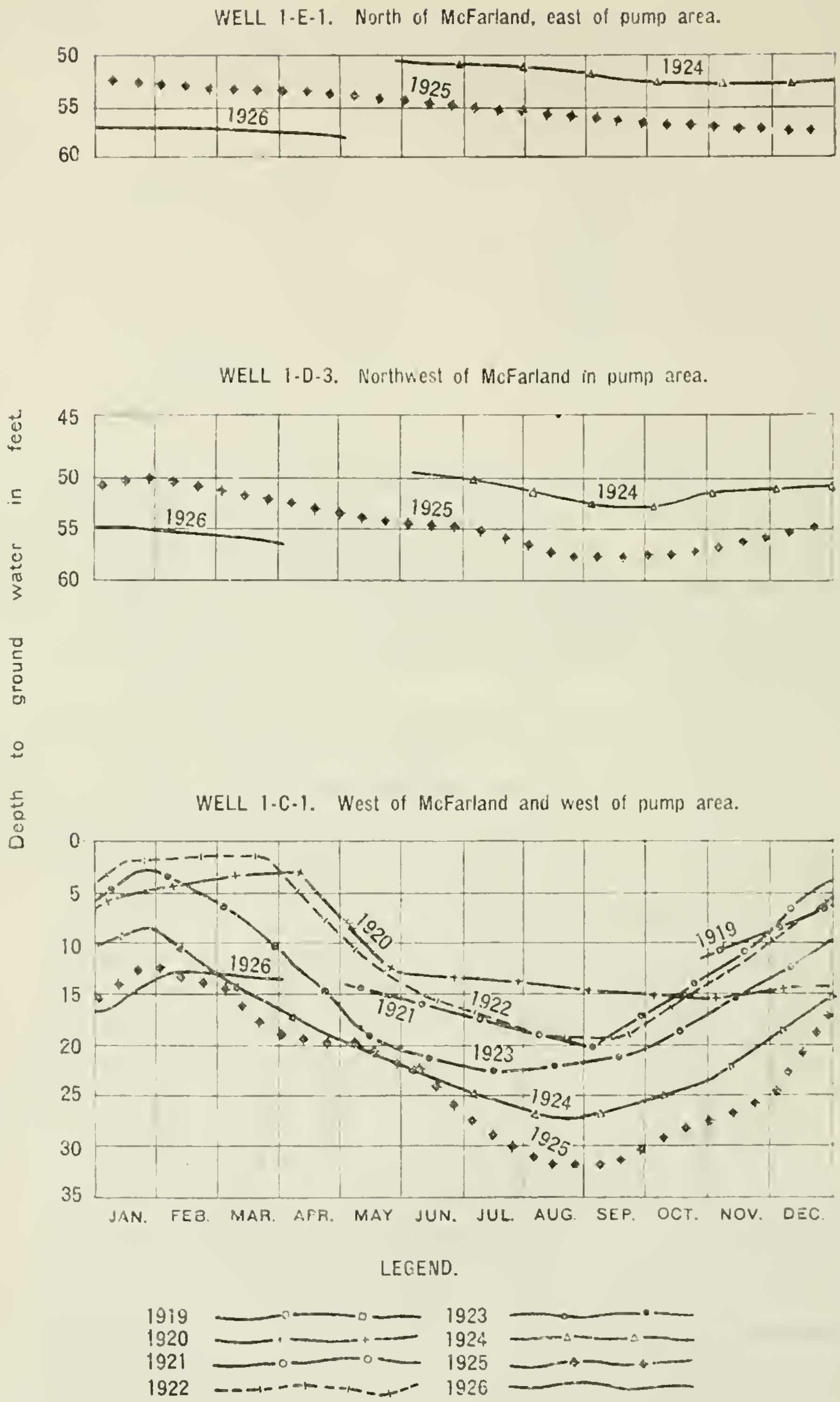


FIG. 28. Hydrographs of typical wells in McFarland Area.

Well 4–D–5 is southwest of Shafter within the pumping area. The lowering during the summer with a rise after the end of the pumping season is shown for all years. A continuous drop from year to year is shown for each year. There is a somewhat larger lowering in 1924 and 1925.

Well 3–C–6 is located southwest of Wasco in the pumping area. Continual lowering is shown from year to year. Recovery occurs when pumping decreases during the winter months, but in no year covered by the records has the recovery been equal to the lowering.

Well 2–D–2 is located north of Wasco in an area receiving some canal service and adjacent to scattered areas of pumping. A rise occurred in 1920 and 1922, some lowering in 1921 and 1923, and marked lowering in 1924 and 1925. This well is about 2 miles south of Poso Creek, but shows no response to flow in upper Poso Creek. Lowering continues during the winter months. Continual movement of ground water through this area is indicated with little increase in the rate of lowering during the summer, due to local pumping. A rise occurs whenever there is adjacent canal irrigation, but such rises are not as marked as in Well 3–D–7 which is nearer to the main canal irrigated areas.

Wells 1–E–1, 1–D–3 and 1–C–1, Fig. 28, are in the McFarland area. Well 1–E–1 is north of McFarland and east of the pumped area. For the period covered by the record a continual and relatively uniform lowering of over 4 feet per year is shown. Well 1–D–3 is west of McFarland within the pumped area. A similar continual lowering is shown with the added effect of summer pumping. Well 1–C–1 is to the west and although only 78 feet deep fluctuates widely between the summer lowering and the winter recovery. Less tendency toward continual lowering is shown. The fluctuations of this well are more nearly representative of those of strata under pressure than of surface water.

The lack of any canal delivery in 1924 furnishes an opportunity to observe the rate at which the the ground water lowered by outflow in the canal area under the Lerdo and Calloway canals. Wells were selected which were also sufficiently to the east of pumping areas to be unaffected directly by such pumping. Ten wells averaged to lower at the rate of 0.65 foot per month in 1924. Of these, 7 wells averaged to lower at the rate of 0.5 foot per month in 1925. The small amount of canal delivery in 1925 together with the lower ground water elevation probably account for the reduced rate of lowering in 1925. A rate of lowering of 0.6 foot per month with a 12.5 per cent drainage factor represents a drainage of 0.95 acre-foot per acre per year. This would appear to be about the rate of outward movement, to be expected to occur, from the higher portion of this area.

The preceding discussion is considered to support the conclusion that pumping in this area has increased until the draft exceeds the present average water supply so that continued ground water lowering is to be anticipated even under normal conditions of water supply. It is considered that the main source of ground water supply in this area is the loss from canal use. Such losses are largely due to present conditions of use. A decrease in the use of water from canals per acre irrigated would reduce the additions to the ground water from such sources and render more acute the ground water problems of this area, unless provision is made for the irrigation from canals of sufficient additional area to supply the ground water. The interest of all users of ground water in the conditions of canal use in this area is a direct one. While Kern River may be able to furnish an adequate water supply for this area if properly regulated, under existing conditions only continued ground water lowering can be anticipated.

GROUND WATER IN NORTHERN KERN COUNTY AREA.

The Kern River Water Storage District does not extend to the northern line of Kern County. There is an area in township 25 south which is outside the influence of conditions within the storage district. The Shafter, Wasco and McFarland area in Kern County includes the area considered to be affected by Poso Creek and by canal irrigation from Kern River.

The only direct local source of water supply for the northern edge of Kern County is Rag Gulch. This has a very limited and irregular run-off, which has been estimated as an average of 3500 acre-feet per year. During the normal seasons the surface flow does not reach very far into the valley. In 1926 heavy local storms resulted in run-off which caused damage to highways and railroads.

The pumping draft in 1921 was estimated as 9100 acre-feet. This has been increased since that time. As the draft materially exceeds the estimated supply, continued lowering is to be expected as long as the present draft is maintained.

Wells Kern 32 and 13, Fig. 20 (shown with wells in White Creek area) are typical of this area. Well Kern 32 is located about 3 miles northwest of Delano. A continuous and steady lowering is indicated by the available records on this well. The rate of lowering appears to be affected but slightly by the character of the individual season. Well Kern 13 is located five miles east of Delano in an area of scattered pumping. A continued and rapid lowering is shown. The ground water in this area is relatively deep.

GROUND WATER IN PIONEER CANAL AREA.

This includes the lands along the Pioneer Canal and irrigated by it. It extends from Kern River to Goose Lake Slough in township 30 south, ranges 25 and 26 east. Canal service is secured from the Pioneer, James and Dixon and the Johnson canals. In addition to the canal irrigated area, about 800 acres are irrigated by pumps.

Ground water records are available only for 1924 and 1925. In 1925 a total diversion of 11,800 acre-feet was used for the irrigation of 3470 acres. The ground water rose an average of 0.04 foot, lowering slightly in the western portion and rising in the eastern.

In addition to the ground water supply received from irrigation, some movement into the area of seepage losses from Kern River below Pioneer weir may occur. Movement may also take place from the Rosedale area. The available data do not permit an estimate to be made of the draft on the ground water which can be supported in this area, although it is larger than the present draft. Supplies now received from upper areas may be at least partially intercepted by changes in methods there.

Conditions for obtaining good yields from wells vary. In the western portion, while water is present in good quantities, the close texture of the water-bearing material makes it difficult to obtain good yields from wells. Five plants operated in 1906 by the Kern County Land Company on their McClung Ranch in the eastern part of the area gave an average discharge of 4.5 second-feet each. With proper installations wells of at least fair discharge should be obtainable in nearly all of this area.

Wells have been drilled recently in sections 21 and 28, township 30 south, range 25 east, by the Western Water Co., which supplies water in the oil fields. These are adjacent to the channel of Kern River. They varied from 105 to 455 feet in depth. Some coarse sand and gravel was encountered. The water was of good quality.

GROUND WATER IN VALLEY TROUGH AREAS SOUTH OF TULARE LAKE.

This area extends from Kern River to Tulare Lake. It extends to the areas previously discussed as the Pioneer, Rosedale, Shafter, Wasco and McFarland and the White and Deer Creek areas on the east and to the hills on the west.

Some ground water inflow from the higher adjacent areas on the south and east occurs. Artesian flow has been obtainable over nearly all of this area in the past. Artesian conditions existed before irrigation began so that natural sources of the artesian supply must furnish at least a portion of this flow. Available records do not permit a determination of whether irrigation on lands to the east has affected the pressure strata in this area as it has the shallow water under the canals.

Ground water development is less extensive and information on its fluctuations is less complete than in the areas to the east.

Goose Lake Slough Area.

This area covers the lands along and adjacent to Goose Lake Slough extending from the Rosedale and Pioneer areas to Goose Lake. There is no canal irrigation in this area. About 5000 acres were irrigated from artesian flow and by pumping in 1920, over two-thirds of the area being pasture. There has been little new development since 1920.

The soil formation is such that percolation does not return to the deeper ground water. The amount used from artesian flow was not determined. However, general appearances indicate a liberal use. The artesian wells are from 500 to 800 feet deep. The area is understood to have been artesian prior to canal irrigation, so that the source of supply appears to be at least partly from seepage from Kern River.

There are no deep wells on which continuous readings have been secured since 1920. One well, 1100 feet deep, lowered 1.5 feet from 1924 to 1925. Six wells, from 100 to 300 feet deep, lowered an average of 5.6 feet in the five years from 1920 to 1925. Twelve wells lowered an average of 1.7 feet from 1924 to 1925. These amounts of lowering are hardly more than might be expected during the dry years of this period. As the larger part of the draft comes from the deeper wells whose source of replenishment appears to be in areas near the river in which pumping is not extensive, there does not appear to be an overdraft on the ground water in this area under existing conditions.

Well 5-C-8, Fig. 29, is typical of the fluctuations of the shallow wells

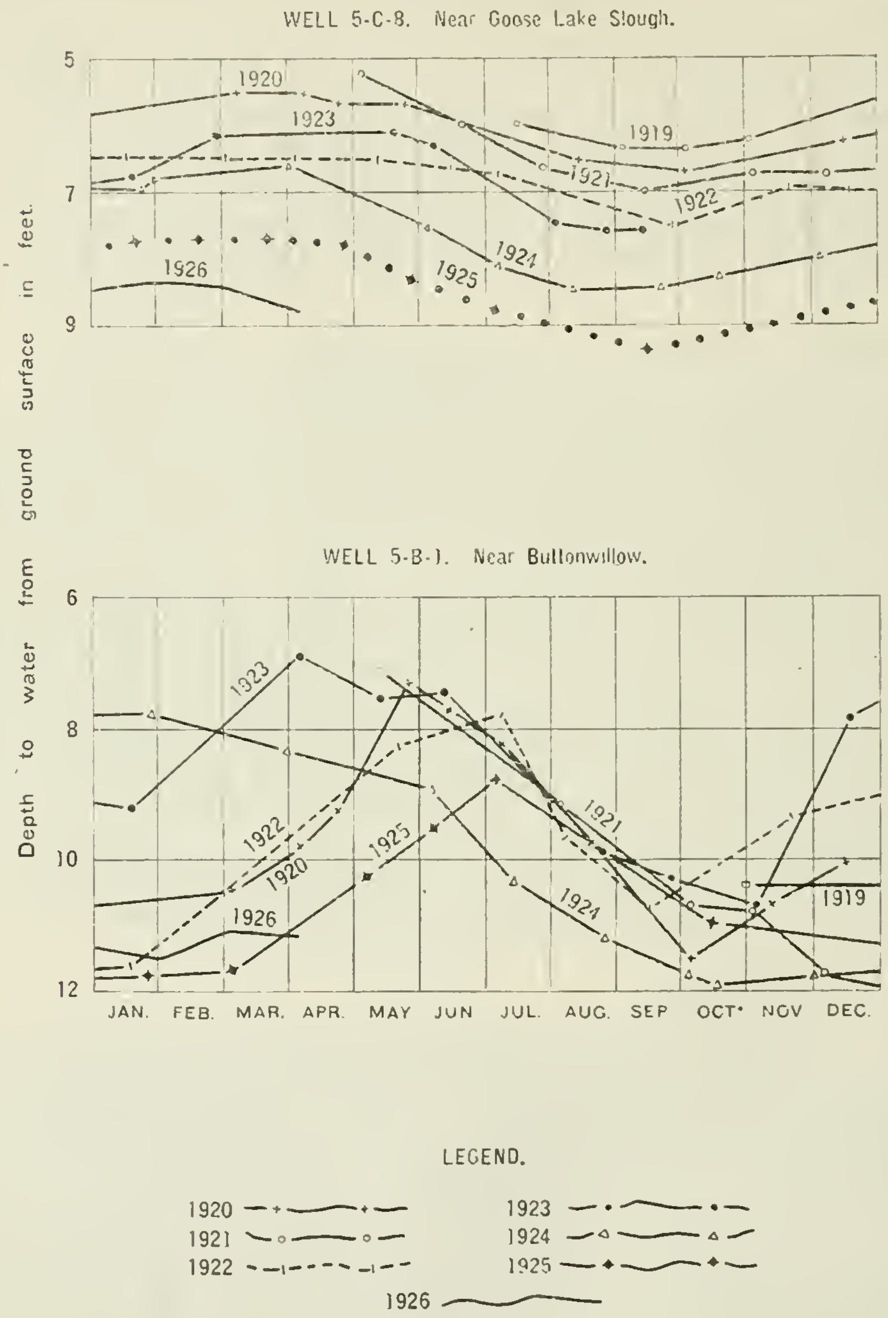


FIG. 29. Hydrographs of typical wells in Goose Lake Slough and Buttonwillow Areas.

in this area, this well being 77 feet deep. The lowering in 1925 and 1926 probably reflects the less seepage flow into Goose Lake Slough in the Rosedale area due to the lower ground water there.

Wells 300 to 500 feet have recently been drilled in sections 21 and 22, township 29 south, range 24 east, west of Goose Lake Slough. Water of good quality was secured.

Buttonwillow Area.

This represents the areas between the East and West Side canals and south of Wasco Road. Much of this area is now within the Buena Vista Water Storage District.

Only limited development of ground water has occurred. Artesian wells are obtainable and have been used to some extent, mainly for stock watering. Water also occurs in shallow strata; the water-bearing materials are generally fine.

Water in the north end of this area is of poor quality. The line shown on Map No. 2 marks the general division between the areas in which waters of good and of poor quality are obtained. This division is based on investigations made for Mr. J. B. Lippincott in 1919, the results of which have been made available. Over the greater portion of the areas the ground water is of suitable quality.

Well 5–B–1, Fig. 29, is typical of the fluctuations under the East Side Canal in this area.

Valley Trough South of Tulare Lake.

This area extends from the Goose Lake Slough and Buttonwillow areas on the south to Tulare Lake on the north and from the Shafter, Wasco and McFarland and the White and Deer Creek areas on the east to the west side of the valley. No canal service from surface sources is received and the ground water development is scattered. The wells are mainly deep and generally artesian. Some wells which formerly flowed continuously now flow only during winter months of light pumping draft. Flowing wells of shallow depth have been secured in some parts of the area.

In 1920 about 5600 acres were irrigated in the portion of this area in Kern County. No detail canvass of the area has been made since 1920. The new development has been less than in the main pumping areas to the east, except for the area used for duck club purposes.

In addition to the draft for local use, the Alpaugh Irrigation District has a battery of wells in sections 27 and 28, township 25 south, range 24 east. This consists of 17 wells, 2 new ones having been added in 1926. No record of the actual draft is available. These wells are pumped during the irrigation season, the water lowering to depths of about 30 feet. The wells usually flow in the winter.

There are also plants in this area used to develop water for use in the oil fields. No record of the amount of this draft is available.

The wells in this area are usually about 500 feet deep with the lower 300 feet perforated. If perforated above this some artesian pressure is lost. Wells in township 26 south average 350 to 500 feet in depth. In township 25 south the wells are deeper, averaging about 800 feet. The wells of the Alpaugh district at Smyrna average 900 feet deep.

There are 12 wells on the La Hacienda Ranch in Kings County in the northern portion of this area varying from 900 to 1200 feet deep. Most of these wells are perforated below 550 feet from the surface. Some of these discharge sufficient gas to furnish power for pumping. Several of these wells are now pumped for irrigation.

Records of 4 wells in this area show an average lowering of 12 feet from 1920 to 1925. Records of 6 wells show an average lowering of 4 feet from 1924 to 1925. This lowering is due to decrease in pressure rather than the draining of soil volume. These wells are relatively sensitive to the draft on adjacent wells. Pumping on artesian wells may cause other artesian wells at some distance to cease flowing.

There is not sufficient use of ground water and record of the effect in this area to enable the extent of the permissible draft to be estimated. Outward movement of ground water apparently occurs in all adjacent areas from which ground water slopes into this area. Part of these sources are natural and existed prior to irrigation, such as losses from Kern River and its overflow; part is artificial, such as the estimated outward movement from the Shafter, Wasco and McFarland area of ground water supplied by canal sources. These sources of supply are apparently in excess of the present draft in this area. How much more draft might be sustained or the extent to which additional development nearer the sources of supply may intercept water now reaching this area can not be predicted on the basis of information now available.

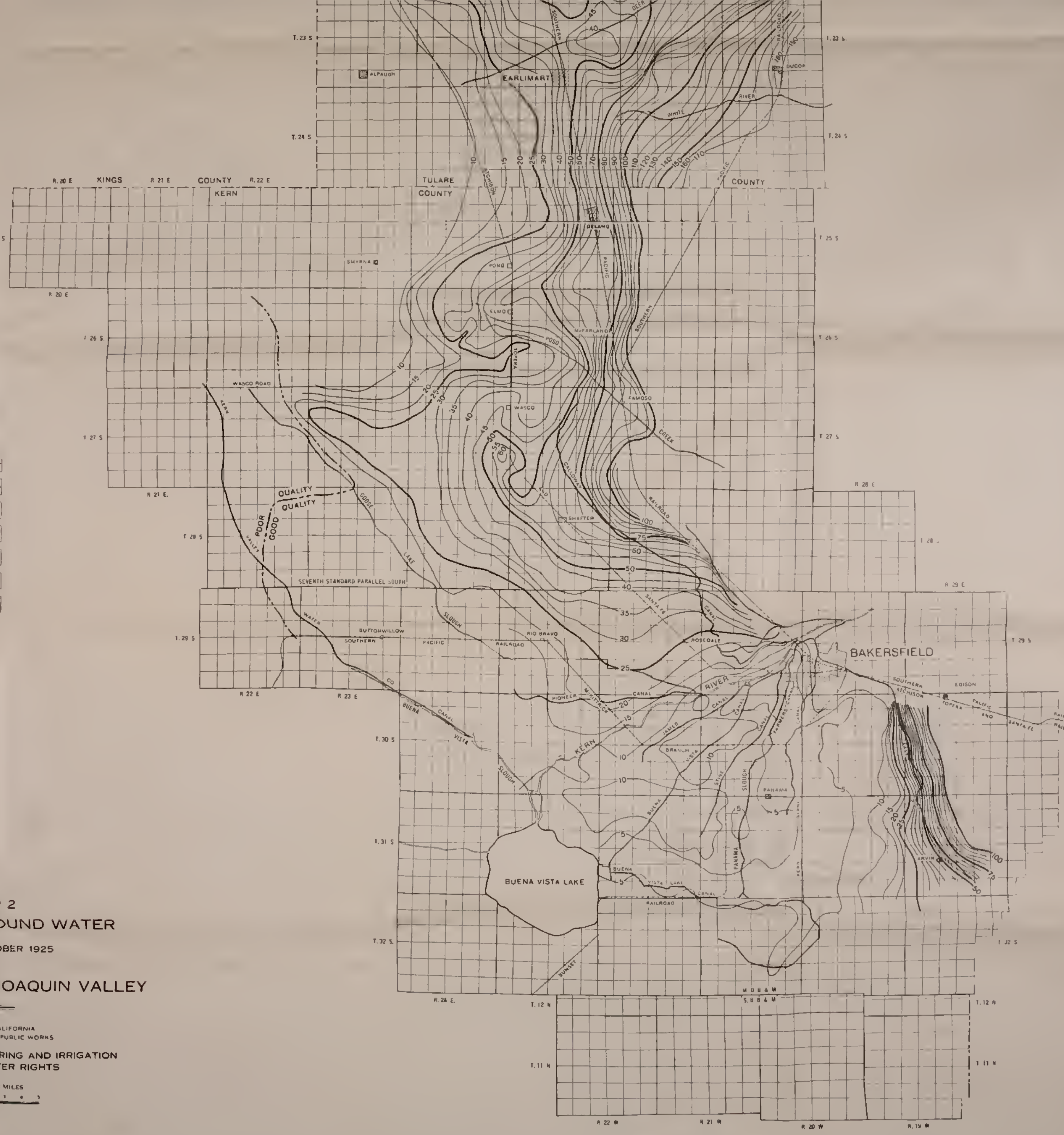
A recent development in the northern portion of this area has been the flooding of land for use as duck ponds. An area of 5000 acres or more mainly in township 25 south, range 23 east, and township 26 south, range 23 east, has been prepared in checks and equipped with pumping plants. Several areas also have clubhouses. Some irrigation for crops, mainly rice, is practiced. The principal purpose of the development is, however, indicated by the signs advertising the lands for sale or lease for gun club use.

While ground water development in this area has not been sufficiently extensive to determine the extent of the available supply, there is sufficient knowledge of the general water supply conditions and the demand for irrigation in this portion of the San Joaquin Valley as a whole to justify the conclusion that there is no water available for non-beneficial purposes. Extensive pumping use for gun club purposes will eventually result in an equivalent reduction in the supply available for irrigation. Whether pumping for duck ponds is of sufficient benefit to entitle it to be practiced as a legal right is a matter outside the scope of this report. As a matter of public policy it would be adverse to the public interest to have use by such gun clubs interfere with or reduce the supply available for agricultural purposes.

o

47076 1-27 3M

SCIENCES
LIBRARY



LEGEND

- COUNTY BOUNDARIES
- AREA AND DISTRICT BOUNDARIES
- DIVISION LINE BETWEEN GROUND WATER OF GOOD QUALITY AND POOR QUALITY
- CANALS
- RAILROADS
- RIVERS AND SLOUGHS
- CONTOURS OF DEPTH TO GROUND WATER IN FEET

MAP 2
DEPTH TO GROUND WATER
AS OF OCTOBER 1925
IN
SOUTHERN SAN JOAQUIN VALLEY

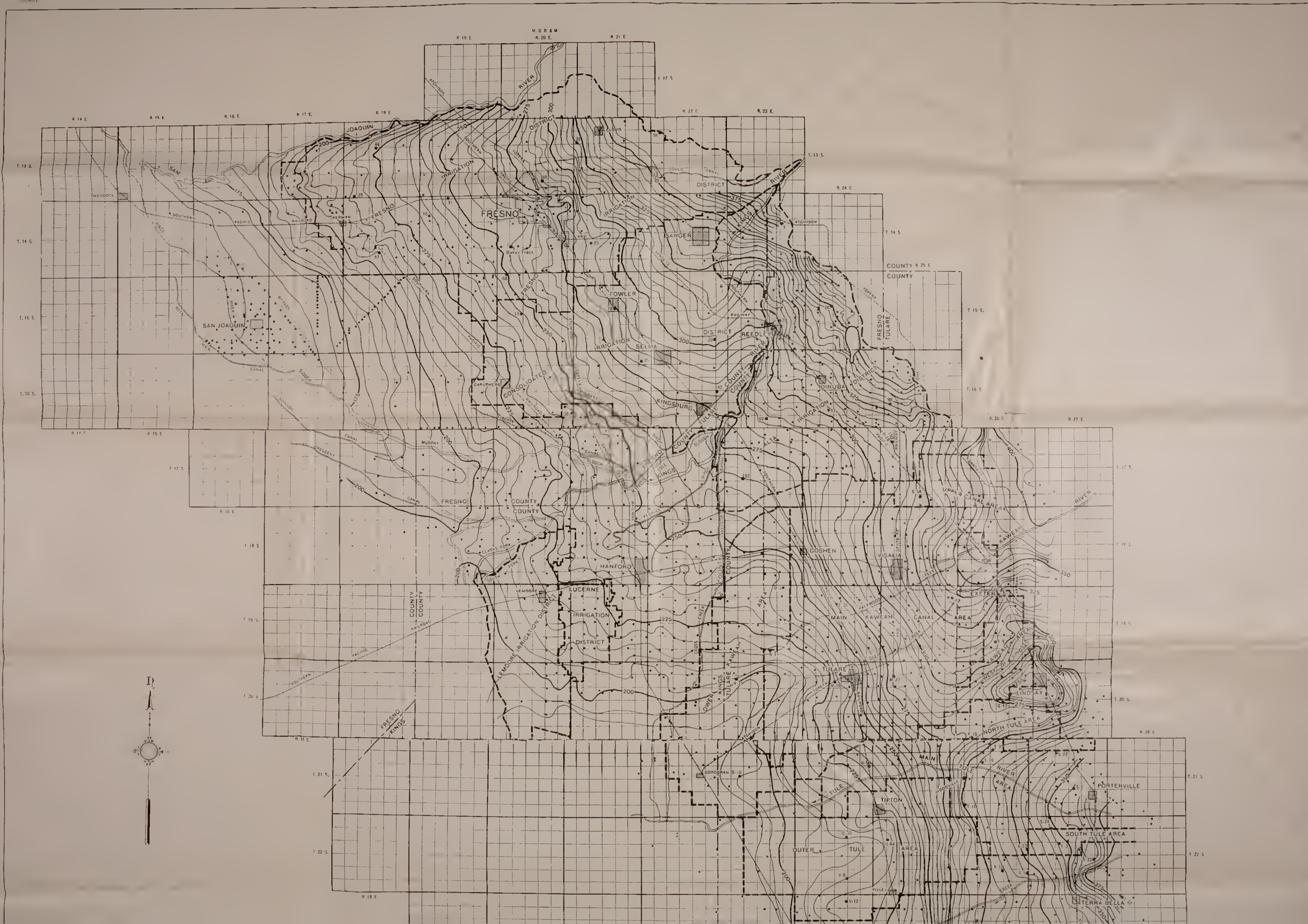
STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS

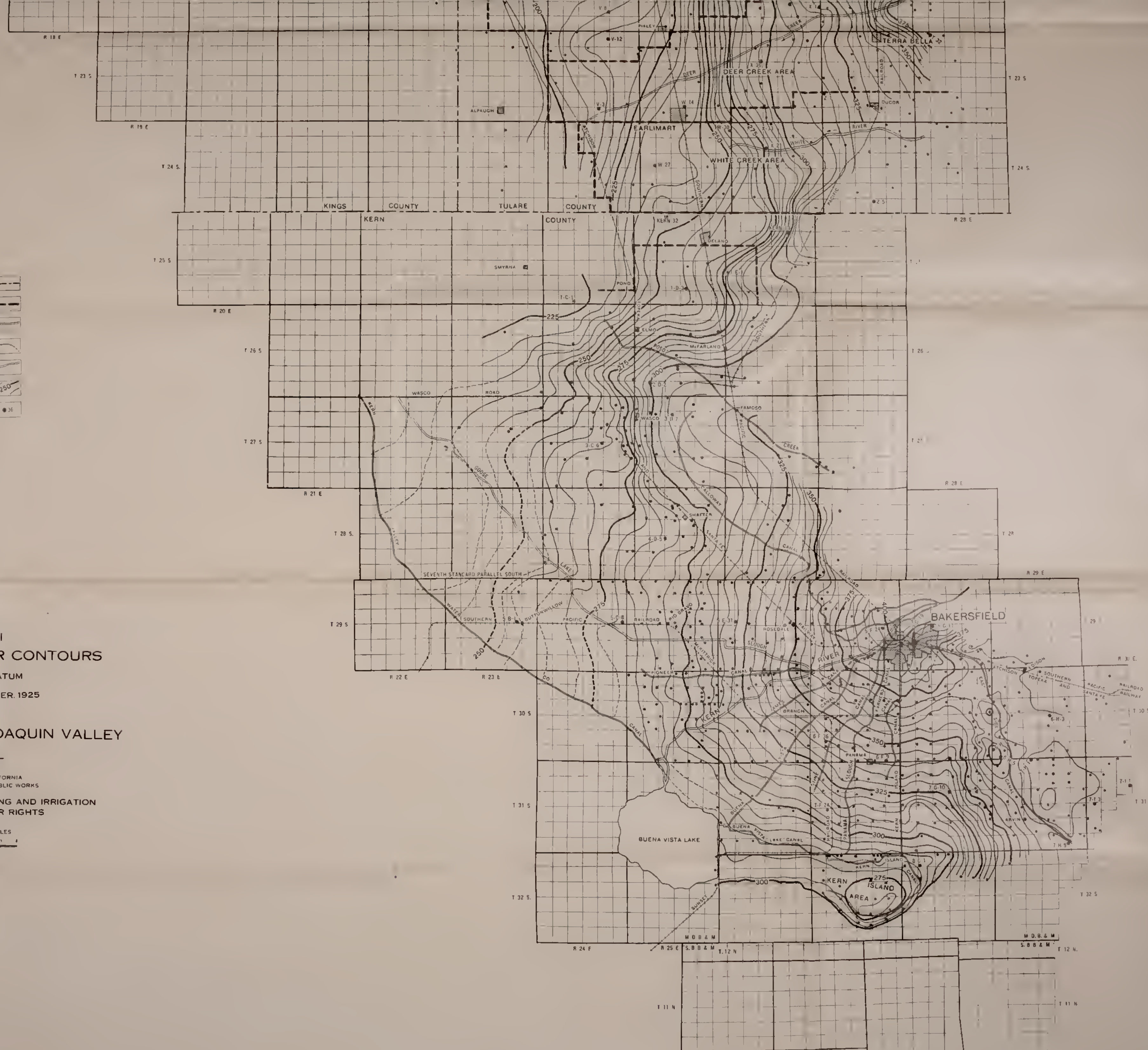
DIVISIONS OF ENGINEERING AND IRRIGATION
AND OF WATER RIGHTS

SCALE IN MILES

PHYSICAL

PHYSICAL
SCIENCES
LIBRARY





LEGEND

- COUNTY BOUNDARIES
- AREA AND DISTRICT BOUNDARIES
- CANALS
- RAILROADS
- RIVERS AND SLOUGHS
- CONTOURS OF GROUND WATER IN FEET
- WELLS

MAP I

GROUND WATER CONTOURS

U.S.G.S. DATUM

AS OF OCTOBER, 1925

IN

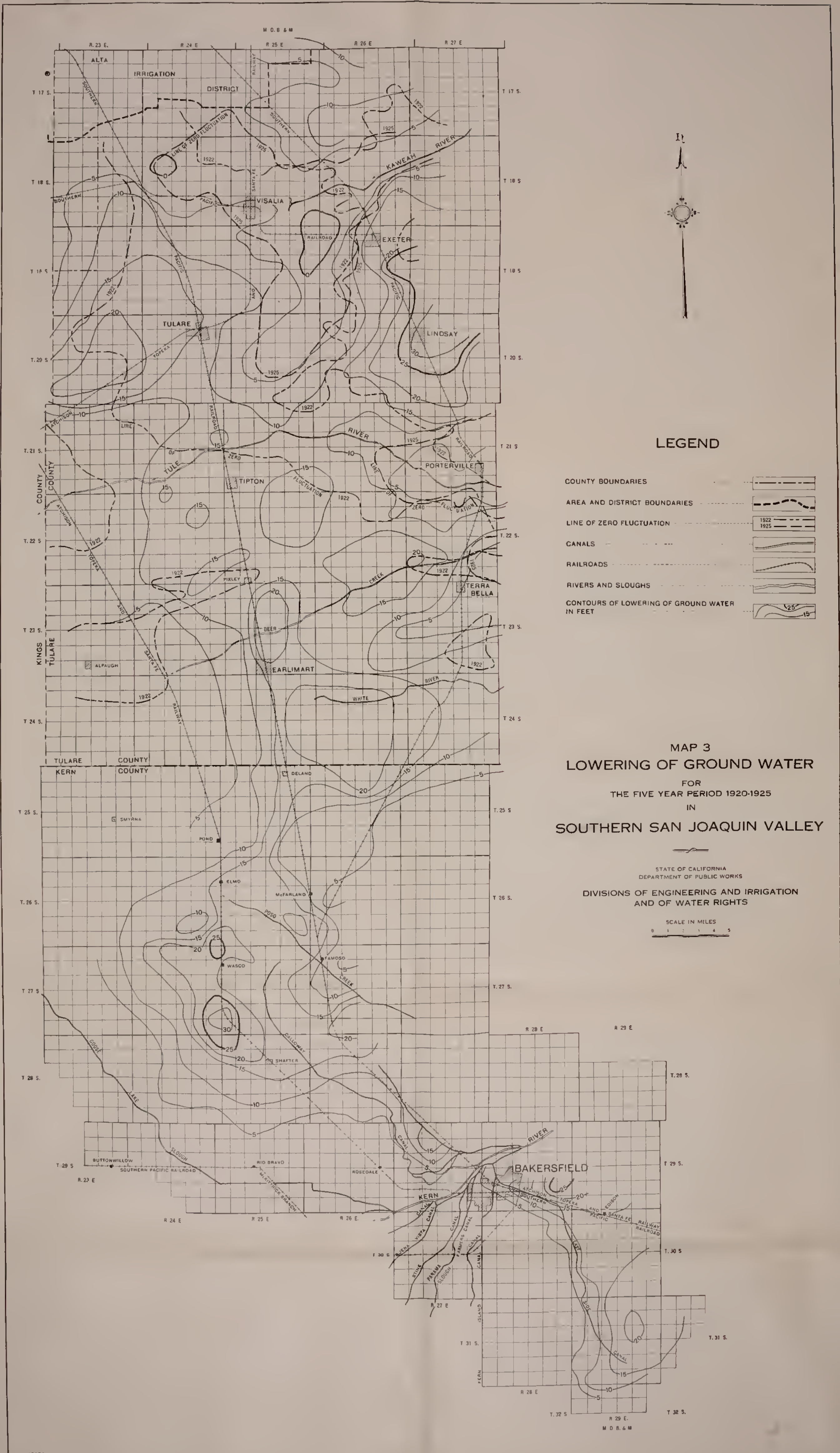
SOUTHERN SAN JOAQUIN VALLEY

STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS

DIVISIONS OF ENGINEERING AND IRRIGATION
AND OF WATER RIGHTS

SCALE IN MILES

PHYSICAL SCIENCES LIBRARY


MAP 3
LOWERING OF GROUND WATER
FOR
THE FIVE YEAR PERIOD 1920-1925
IN
SOUTHERN SAN JOAQUIN VALLEY
STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISIONS OF ENGINEERING AND IRRIGATION
AND OF WATER RIGHTS
SCALE IN MILES
LEGEND
COUNTY BOUNDARIES
AREA AND DISTRICT BOUNDARIES
LINE OF ZERO FLUCTUATION
1922
1925
CANALS
RAILROADS
RIVERS AND SLOUGHS
CONTOURS OF LOWERING OF GROUND WATER IN FEET
ALTA IRRIGATION DISTRICT
VISALIA
EXETER
TULARE
LINDSAY
KAWEAH RIVER
TIPTON
PORTERVILLE
TULE RIVER
LINE OF ZERO FLUCTUATION
TERRA BELLA
PIXLEY
DEER CREEK
EARLIMART
WHITE RIVER
ALPAUGH
KINGS COUNTY
TULARE COUNTY
KERN COUNTY
DELANO
SMYRNA
POND
ELMO
McFARLAND
POSO CREEK
FAMOSO
WASCO
SHAFTER
GOOSE LAKE SLOUGH
BUTTONWILLOW
SOUTHERN PACIFIC RAILROAD
RIO BRAVO
ROSEDALE
BAKERSFIELD
KERN RIVER
ATCHISON TOPEKA AND SANTA FE RAILWAY
SOUTHERN PACIFIC
M.D.B.&M.

47076

THIS BOOK IS DUE ON THE LAST DATE STAMPED BELOW

BOOKS REQUESTED BY ANOTHER BORROWER ARE SUBJECT TO IMMEDIATE RECALL

RECEIVED
FEB 20 1988 AY
PHYS SCI LIBRARY

JUN 07 1990

JUN 27 1990 REC'D

RECEIVED
JUN 29 1990
PHYS SCI LIBRARY

RECEIVED
SEP 19 1996

APR 13 2000

JAN 19 2000

JAN 27 2000 REC'D
6/14/00

AUG 28 2000 REC'D

RECEIVED
AUG 29 2000
PSL

LIBRARY, UNIVERSITY OF CALIFORNIA, DAVIS

Book Slip–Series 458

3 1175 00671 2015

Calif,
PHYSICAL
SCIENCES
LIBRARY

TC824
C2
A2
no.11-13

Collate:
3 Maps in
Pocket

LIBRARY
UNIVERSITY OF CALIFORNIA
DAVIS
111583